Lubricating Oils: Carbon Residue Estimation. The Ramsbottom Method.*

By C. I. Kelly, M.Sc. (Tech.), F.I.C., F.C.S. (Associate Member).

Historical.

The formation of carbon deposits in petrol and other engines has been noticed ever since these engines were used, and endeavours have repeatedly been made to devise some means for selecting out of a number of lubricating oils, the one which would give the least " carbon " in practice. Having this object in view, H. Souther[1] used a method which was carried out by distilling 40 grams of oil in a 100 ml. glass retort at a rate of 4 to 5 drops per minute, the whole test taking about 30 minutes. When the retort was nearly dry, the flame was increased and applied all over the outside of the retort. Complete removal of the oil vapours was accomplished by blowing through the retort while heating during the final period. By this means Souther was able to select a suitable oil for automobile engines and he considered an oil of over 0·5 per cent. carbon residue to be unsuitable.

The method now used in most laboratories appeared in its original form a few years later. P. H. Conradson[2] described the method, which consisted of distilling oil contained in a glass crystallising dish, or platinum dish (which was placed in an iron crucible or retort) under specified conditions.

Further development of a laboratory method for carrying out a carbon residue test was promoted by the American Society for Testing Materials, and the first step in the activities of this society consisted in the putting forward of T. T. Gray's Carbon Residue Method[3], as one of a number of proposed tests on lubricating oil. Gray's method is similar to that described six years earlier by Souther, in that he proposed the distillation of 25 ml. of oil from a flask having a bulb $1\frac{3}{4}$ inches in diameter, the other dimensions also being quoted. The side arm of the flask was connected to a small aerial condenser, the rate of heating being adjusted by follow-

* Paper received July 8, 1929. A précis of this paper will be found in Abstract No. 626.

[1] *Proc. Amer. Soc. Testing Materials*, 1908, **8**, 593.
[2] *Eighth Intern. Congr. Appl. Chem.*, 1912, **1**, 131-2; *J. Ind. Eng Chem.*, **4**, 903-5.
[3] *Proc. Amer. Soc. Testing Materials*, 1914, **14** (i.), 364.

ing the rate of distillate formation. Finally, the flask was heated strongly till no more fumes were given off and after having burnt the oil and carbon out of the neck down to the side arm and also out of the side arm, the flask was again weighed.

Three years later the A.S.T.M. published details of a tentative Carbon Residue Test for Lubricants, Serial Designation, D. 47–17T.[4] It was a modification of the method described by P. H. Conradson five years earlier. The method was adopted as a Standard in 1918 and revised in 1921. In 1924, it was withdrawn and published as a tentative method. This step was taken because two oils were circulated by Sub-Committee 23 among six laboratories, so that they might be tested by the Standard method. The results of these experiments were published in *Proc. Amer. Soc. Testing Materials*, 1924, **24**, 569, and showed that the method of heating, which was, in their opinion, probably the most important factor in the conduct of the test, was not sufficiently under control. The result was that tests of the same oil, carried out by different observers in the same laboratory, varied considerably. (In one laboratory one oil gave results varying between 10·07 per cent. and 12 per cent.; in another laboratory, a different oil gave results ranging from 4·07 to 4·69 per cent.)

The fact that temperature control was probably the most important factor was emphasised by W. M. Seaber[5], who heated the oils in an improvised electrically heated oven in which the temperature was controlled to within ± 5° F., and he showed that more concordant results could be obtained from the Conradson Test by controlling the temperature within the limits stated.

F. Schulz and M. Kohout[6] considered the test unreliable because it was subject to a number of experimental errors. They suggested that a good procedure was to take 2 grams of oil in a Merk Rosenthal porcelain crucible 103 No. 4, which should be placed in a cold Conradson apparatus. The apparatus should then be heated for 20 minutes with a Tirrell Burner over a flame 20 cm. long with the bottom of the iron crucible held 5 cm. from the orifice of the burner.

However, Sub-Committee 23 of the A.S.T.M. carried out further work and issued a report[7] in which the method was described in greater detail, and the results published indicated that, in order to obtain concordant results, the heat must be applied in a definite manner and for a definite time. Six laboratories sent in average tests on one oil, ranging from 1·29 to 1·80 per cent. On another oil the averages ranged from 0·62 to 0·646 per cent. (duplicate tests

[4] *Proc. Amer. Soc. Testing Material*, 1917, **17** (i.), 770.
[5] *Ind. Chemist*, 1925, **1**, 22-3, 79-80.
[6] *Petroleum Z.*, 1927, **23**, 554-7.
[7] *Proc. Amer. Soc. Testing Materials*, 1927, **27**, (i.), 473.

on this oil in one laboratory were 0·684 and 0·531). The results on a third oil varied from 0·35 to 0·385 per cent., and on a fourth oil from 0·13 to 0·165 per cent. This report also gave results obtained on another oil, obtained under varying condition of heating. When the burning period was 18·5 minutes in duration (slow) the result obtained was 1·95 per cent., and when this period was cut down to 9·5 minutes (fast) the result was 1·62 per cent.

The tentative method, Serial Designation D.181–27T, adopted as a Standard in 1928 differs from the tentative method of 1924 inasmuch as (1) 2 glass beads 0·1 inch diameter shall be put in the crucible before weighing, (2) It specifically states that the oil shall be free from moisture, (3) It limits the pre-ignition period to 10 mins. (± 1½), and (4) It limits the final heating period to 7 minutes, the total period of heating to be 30 mins. (± 2 mins.). (A typical example gives a pre-ignition period of 11 mins., a burning period of 11 mins., and a final heating period of 7 mins.) It also states that the weight of the oil shall be accurate to 5 mgms., and allows *a tolerance on the carbon residue of not more than* 10 *per cent. from an average.*

Endeavours have also been made in this country to arrive at an accurate method of estimating Carbon residue. The method referred to was devised by Dr. J. E. Ramsbottom of the Royal Aircraft Establishment, Farnborough, in 1920 (private communication to the author) and reference is made to it in "Lubricating and Allied Oils," E. A. Evans, 1921, and in "Lubrication and Lubricants," Archbutt and Deeley, 1927.

Whilst the method has met with favour in those laboratories in which it has been used for several years, further interest is added to it, inasmuch as the Institution of Petroleum Technologists has adopted it as a Standard Method under the title of "I.P.T. Serial Designation—G.O. 9a." The method given†, however, describes what *has* to be done, but does not mention *how* it should be carried out on a routine scale. In view of this, experiences with two types of apparata for carrying out this test are put forward.

Description of Apparata.

The former apparatus (see Fig. 1) used for carrying out the above was similar in most details to that previously in use in other laboratories. It consisted of a cast-iron saucepan which, when in use, contained the molten solder to within ¼ inch of the brim. The saucepan rested on, and was heated by, a stout ring gas burner.

In order to carry out several tests at the same time, four iron sheaths of standard dimensions were brazed to a central rod.

† "Standard Methods of Testing Petroleum and its Products." 2nd edition, 1929.

The pyrometer was held in an inclined position so that the end of the pyrometer was against and level with the lower end of one of the sheaths. The original pyrometer had a quartz sheath to

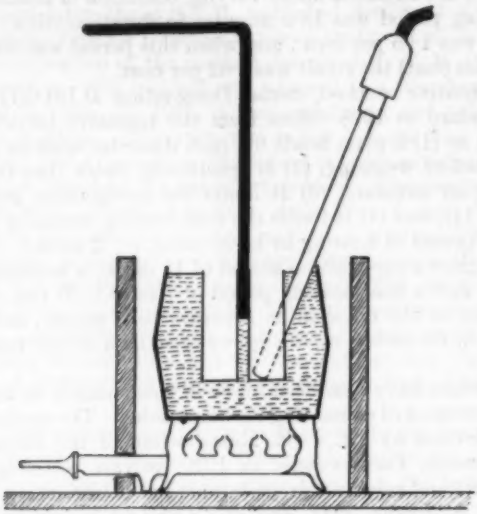


FIG. 1.

protect the bi-metallic element, but on one occasion it was left in the metal when the bath was allowed to cool. On reheating the apparatus, the sheath was found to have been fractured, so the pyrometer was then provided with a thin iron sheath. This did away with the need of removing the pyrometer from the bath before the metal was allowed to solidify—a precaution which is very necessary if a quartz-sheathed pyrometer is used. (The use of an iron sheath has its disadvantages which are pointed out later in the paper.)

The main difficulties experienced with this apparatus were :—

(1) First attempts to heat this apparatus to the required temperature were made difficult on account of excessive radiation. When the gas pressure was low, it was found almost impossible to reach 550° C. This difficulty was more or less removed by shielding the apparatus from draughts, etc., by a cylinder of asbestos (the lower edge of which was turreted), which left an annular space around the saucepan.

(2) The apparatus was not very easy to manipulate, and temperature control was never satisfactory. (Satisfactory temperature control was only obtained when the gas pressure was automatically controlled.)

(3) The main objectionable feature of the apparatus was that when the bath was heated rapidly from cold, with the gas fully turned on, pressure was developed in the lower liquefied portion, and small fountains of molten solder appeared at fissures in the surface of the metal which was still solid. When this occurred, a little solder would get into one or more of the iron sheaths. This meant removing the nest of sheaths and cleaning them out while still hot. On occasions, a little solder would get into one or more of the sheaths unknown to the operator. Any coke tests done subsequent to this would have small particles of solder adhering to the coking bulbs. In some cases these particles could be easily removed, but in many cases all endeavours to remove the adhering solder were completely frustrated, because a permanent glaze had been formed between the metal and the glass. The error introduced by this one cause alone was always discomforting, and repeat tests were thus rendered necessary. (The above difficulty is hinted at in the description of the Standard Method.)

(4) The placing of the glass coking bulb in the iron sheaths was difficult, because the operator's hand and arm had to be held momentarily across the top of the bath and the annular space up which the hot flame from the burner ascended. The glass tube was held by the capillary in a long crucible tongs which had to be held in a vertical position so as to place the coking bulb gently into the iron sheath (the tube, if dropped into the sheath, would probably fracture). Serious burns were occasionally received in this way.

(5) The depth of liquid solder in the saucepan when charged to within ¼-inch of the brim was 4 inches. The length of the iron sheaths was 3 inches, so that the bottom of the sheath would be about 1 inch away from the bottom of the saucepan. In all probability, therefore, the temperature of the sheath varied considerably along its length.

(6) Only the outer parts of the sheaths were in direct contact with the liquid metal.

(7) With an exposed surface, dross rapidly formed on the solder. This had to be removed frequently and the bulk of metal made up with fresh solder.

(8) The cast-iron saucepan would be brittle at 550° C., and fracture due to accidental knocks would be possible.

To remove all these objections an entirely different apparatus was assembled which has given very satisfactory working for eighteen months to date. The model (see Fig. 2) consisted of five

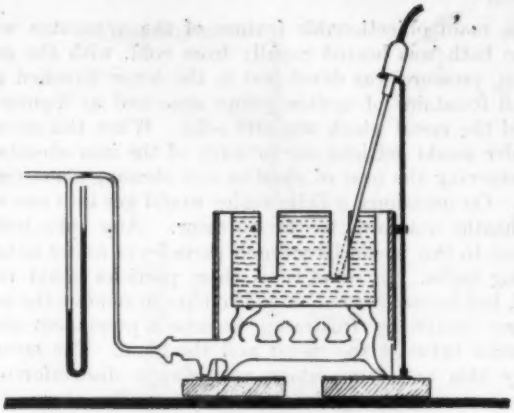


FIG. 2.

pieces. The seams and joints were welded and the material used was mild steel.

(1) The pot or container for the molten metal was made from sheet metal.

(2) A strong squat ring gas burner.

(3) An upper cylindrical part. The top circular plate had six holes drilled in it; these holes were 1 inch in diameter and their centres were on a circle concentric with the edge of the plate. The sheaths, which were of standard dimensions excepting in length (which was 3½ inches), were welded on to the underside of this top plate, so that the holes in the plate were continuous with the insides of the sheaths. A seventh hole was also drilled into the top plate, so that the pyrometer could be inserted into the metal bath. From this top plate hung a cylindrical skirt made of thin sheet mild steel, the inside of which was lined with a layer of asbestos. This insulated skirt had a small circular movable mica window fitted in it so that when assembled the burner could be lit up and viewed from outside.

(4) A lower part. The base plate was circular, and in the centre of this there was a circular hole. On this base plate a cylinder was welded. The outer diameter of this cylinder was slightly

smaller than the inner diameter of the skirt of the upper part, so that it was an easy sliding fit into the latter.

(5) A vertical rod. This passed through a cylinder welded to the skirt of the upper part and rested in a ferrule welded on to the base plate of the lower part. This rod had a circular eye welded on the top, so that the pyrometer could be rested on it and kept in an inclined position. The rod was of such a height that the lower end of the pyrometer took up a position between and level with the lower ends of two of the sheaths fixed to the upper part.

(6) A circular asbestos pad had a channel cut out symmetrically about a radius of the circle. This pad acted as the bed on which the apparatus rested. The lower part is placed on the pad so that the central hole in the base plate is above the channel. (It should be noted that the vertical portion on the base plate and the skirt have semi-circular portions cut away in order to allow the arm of the burner to extend out of the apparatus, and that unless the upper part is heavy enough, the upper part will float on the metal by reason of the buoyancy of the metal which is displaced by the six sheaths which are now immersed in the molten metal.) The rod which is used as a support for the pyrometer is slid through the cylinder, welded to the upper part, and the foot of the rod is placed in the ferrule welded to the base plate. The pyrometer is threaded through the eye on top of the rod and through the seventh hole in the top plate.

The molten metal when at 550° C. reaches to within ¼-inch of the rim of the pot and the lower surface of the top plate, so that the sheaths are immersed to the extent of 3¼ inches in the molten metal.

The Features of the Apparatus.

(1) *Heating-up Period.*—The whole apparatus is well insulated and radiation is at a minimum. Whereas it was often found difficult to raise the old apparatus to 550° C. in reasonable time, this apparatus can be heated up in 1½ hours.

(2) *Temperature Control.*—As the apparatus is well lagged, temperature control is fairly simple. It is necessary, however, to place a manometer in the gas line leading from the bench tap to the nozzle of the ring burner. By this means one is able to follow the difference between the pressure of gas behind the nozzle and the atmospheric pressure. The amount of gas passing through the burner is controlled preferably by a needle valve.

The gas pressure at the exit of the gas meter used is about 9–10 cm. of water. When the gas is full on to the ring burner, the pressure difference recorded by the manometer is about 6–7 cm. of water.

This pressure suffices to allow the apparatus to warm up to 550° C. in 1½ hours. When the temperature recorded by the pyrometer is 548° C., the gas is turned down until the pressure difference in the manometer is equal to a predetermined amount. In the case of the above apparatus, this pressure difference is 4·0 cm. of water. The temperature then gradually rises to 550° C., and remains steady for several hours.

It is obvious that the gas pressure on the meter side of the bench tap must remain steady within reasonable limits, otherwise small adjustments of the needle valve will have to be made from time to time to keep the pressure difference in the manometer at a steady value. (A fairly steady gas pressure can be obtained by fitting a Sugg-governor between the gas meter and the laboratory.) There are times, however, when a large consumption of gas in other parts of the laboratory affect the gas pressure controlled in this way. The only satisfactory way then is to regulate the gas pressure by an automatic regulator, which has been used with excellent success. When this regulator is placed between the bench tap and the needle valve, and when the temperature of the bath has reached 550° C. in the manner described, the temperature will remain steady for the rest of the day. (The author hopes to describe this regulator at a later date.)

Great attention must be paid to this question of temperature control, because the results obtained for the Ramsbottom Carbon residue vary with the temperature.

(3) *Entry of lead or solder into the iron sheaths.*—Liquid metal fountains cannot give trouble with this type of apparatus. Liquid metal from the bath cannot find its way into the sheaths.

(4) *Danger of Burns.*—There is very little discomfort attached to the placing of the glass coke bulbs in the sheaths.

(5) *Convection Currents in the molten metal.*—Convection currents in the liquid contents of the pot are at a minimum because the flame from the burner not only heats the base of the pot, but also partly envelops the sides of the pot. The upper part of the pot is also surrounded by the hot products of combustion. The surface of the liquid metal is protected from cold air by the top plate. The centres of the sheaths are also equi-distant from the central axis and the sides of the pot.

(6) *Independent Suspension of Sheaths.*—An important feature of this apparatus is that the sheaths are independently suspended in the liquid metal, so that all the sides of the sheaths are in contact with the molten lead.

(7) *Dross Formation.*—Dross formation on the surface of the molten metal is cut down to a minimum, because the surface is

more or less sealed off from the outside air. (After eighteen months of frequent use only a thin layer—$\frac{1}{16}$-inch—of dross had formed on this type of apparatus.)

(8) *Fracture of Pot.*—The pot having been made of mild steel and being protected by the outer part of the apparatus, is free from accidental fracture.

(9) *Cooling of Burner.*—The apparatus being completely enclosed causes the ring burner to become very hot, and it assumes a dull red heat. For this reason, the secondary air is introduced to the inside of the apparatus through the circular hole in the base plate, so that it first of all encounters the underside of the ring burner and keeps it cooler than it would be otherwise. At the same time, the secondary air is somewhat preheated.

(It should be pointed out that the products of combustion leave the annular space around the pot through a small chimney welded at the top of the cylindrical skirt of the upper part of the apparatus.)

(10) *Number of simultaneous estimations.*—Six estimations can be done at the same time.

(11) *Asbestos Pit around Apparatus.*—Should accidental spilling of lead or fracture of the bath take place, one would be faced with the pouring over the bench of 80 to 100 pounds of molten lead at 550° C. As a precaution against the consequences, the apparatus is placed in a wooden tray lined with asbestos. If for some reason the lead should flow out of the apparatus it would be retained in the shallow asbestos-lined pit.

Experimental.

Introduction of Oil into Coking Bulbs.—There are two methods of introducing oil into the bulbs other than that described in the Standard Method.

(1) A volume of oil, measured in a squat measuring cylinder, may be warmed up and poured into the bulb through a small capillary funnel made from $\frac{1}{2}$-inch glass tubing, drawn out to a capillary. There is an objection to this method, in so far as one has to clean both the funnel and the measuring cylinder after each oil has been dealt with.

(2) The weighed bulb may be heated over a burner to expel some of the air. The bulb should then be placed capillary downwards in a 30 ml. crucible containing the oil, and as it cools, oil is drawn into the bulb (see Fig. 3). After a little experience the bulb can be withdrawn when 4 to 4·5 grams of oil have entered. After a rough checking of the weight, the oil in excess of 4 grms. may be ejected by inverting the bulb and warming the base gently. (Three drops

of oil are equivalent to about 0·1 grm.) The process of filling by this method takes 2½-3 minutes, and there is very little risk of contaminating one oil with another as the crucible in easily cleaned.

FIG. 3.

The Effects of the Variables on the Result.—A number of estimations were carried out on the present form of apparatus (Fig. 2), with a view to ascertaining the effects of the variables, which may exert an influence on the result obtained.

(1) *The Equality of the Six Sheaths.*—Table 1 gives the results of six determinations on the same oil "A" carried out alongside each other, and it indicates that there is very little difference, if any, between the behaviour of the coking bulbs in the six sheaths.

TABLE 1.

EQUALITY OF THE SIX SHEATHS.

(Temperature 550° C.)

Oil.		Weight of oil taken. grs.	Weight of bulb empty. grs.	Weight of carbon residue. grs.	Per cent. of carbon residue.
A.	1.	3·9255	6·1675	0·0205	0·522
	2.	3·8682	7·9885	0·0210	0·542
	3.	3·8637	5·2203	0·0207	0·536
	4.	3·9627	5·5250	0·0213	0·537
	5.	3·9157	5·6598	0·0215	0·55
	6.	4·0758	5·7657	0·0218	0·535

The six results lie between the limits of 0·52 and 0·55 per cent. The range is roughly 6 per cent. on the result. The difference could be due in the main to temperature variations in the bath of metal (see Temperature Variation Effects, p. 508). Assuming the conclusions in this section to be correct, within reasonable limits, then, if sheath 1 were 7° C. hotter than sheath 5 (which is very probable), one would get the results 0·52 and 0·55 respectively, everything else being constant. Therefore, unless the contents of the bath are vigorously agitated, one cannot expect to obtain a set of six results to agree within less than the above limits.

(2) *The interval between the removal of one set of bulbs and introduction of the next set.*—Several sets of six determinations may be carried out in quick succession without the results obtained from the later sets being affected by temperature variations of the sheaths. During the first 2–3 minutes after placing the bulbs in the sheaths, the temperature change recorded by the pyrometer, the end of which fits closely between two sheaths, is from –1 to –2° C. This decrease in temperature, which is localised around the sheaths, only lasts for a few minutes and the temperature ascends to 550° C. before the fumes cease to be emitted. After one set of bulbs has been removed another set of six may be introduced immediately. Three sets of six determinations on Oil A were carried out in one hour, and the eighteen results were within the range of 0·52 to 0·55 per cent.

(3) *The final heating period.*—Table 2 illustrates this point. Tests were done on oils A, B, C, D, E, F, which cover a range of 0·4 to 5·5 per cent. Carbon Residue. Bulbs were removed after periods of 5, 10 and 15 minutes, timed from the cessation of fuming. The greatest carbon residue is obtained when the final heating period

TABLE 2.

FINAL HEATING PERIOD.

(Temperature 550° C.)

Oil.	Weight of oil taken.	Weight of bulb empty.	Weight of carbon residue.	Per cent. of carbon residue.	Final heating period in minutes.
	grs.	grs.	gr.		
B.	3·9842	7·0468	0·0157	0·394	5
	3·9215	6·8385	0·0152	0·387	10
	4·0035	8·1885	0·0135	0·340	15
A.	3·9650	8·4630	0·0220	0·555	5
	3·9353	6·3942	0·0226	0·574	
	3·9714	6·7393	0·0209	0·526	10
	4·0033	8·1052	0·0218	0·544	
	3·9465	8·4325	0·0207	0·525	15
	3·9735	6·0385	0·0206	0·520	
C.	3·9818	8·4042	0·0381	0·957	5
	4·0840	7·9275	0·0395	0·967	10
	4·2547	7·5588	0·0390	0·920	15
D.	3·9850	6·7070	0·0578	1·45	5
	3·7603	8·2517	0·0548	1·46	10
	4·0218	8·1337	0·0561	1·40	15
E.	4·0297	7·7560	0·0818	2·02	5
	4·0142	7·8508	0·0802	2·00	
	4·0140	7·8375	0·0800	1·99	10
	4·0113	8·0957	0·0808	2·01	
	3·8830	6·8705	0·0760	1·96	15
F.	3·8218	6·6062	0·2093	5·47	5
	4·0690	8·4245	0·2218	5·45	10
	3·9886	7·0475	0·2191	5·49	15

is least, but the percentage difference is greatest on oils of low carbon residue and amounts to approximately 14 per cent. on an oil of 0·4 per cent. carbon residue. This variable has very little effect on results of 2 to 5 per cent.

(4) *Variations in the weight of oil taken.*—Table 3 gives the results obtained on five oils A, G, H, I, J, on which tests were done using 2, 4 and 5·5 grm. of oil. In each case the carbon residue is higher, the smaller the weight of oil taken. The highest percentage differ-

TABLE 3.

Variation in weight of oil taken.

(Temperature 550° C.)

Oil.	Weight of oil taken.	Weight of bulb empty.	Weight of carbon residue.	Per cent. of carbon residue.
	Grs.	Grs.	Gr.	
G.	2·0480	9·4750	0·0082	0·40
	4·0040	8·3110	0·0125	0·31
	5·4325	8·1785	0·0170	0·31
A.	2·4870	8·9255	0·0148	0·595
	2·5147	6·8003	0·0147	0·585
	2·4110	7·6490	0·0143	0·594
	2·5420	7·4390	0·0153	0·602
	4·0045	6·8255	0·0208	0·52
	3·9763	5·6572	0·0208	0·523
	3·9300	8·2920	0·0214	0·545
	4·0451	7·8492	0·0210	0·52
	5·3185	5·4385	0·0262	0·493
	5·4868	6·7897	0·0280	0·51
	5·5695	8·7370	0·0287	0·515
	5·4238	7·9447	0·0271	0·498
H.	2·0745	9·3100	0·0175	0·84
	3·9917	9·1290	0·0280	0·73
	5·0967	8·5133	0·0357	0·70
I.	2·0170	9·6030	0·0392	1·94
	4·0170	9·5885	0·0772	1·92
	5·4120	9·3815	0·1015	1·88
J.	1·9970	9·1475	0·1068	5·35
	3·9735	9·3385	0·2070	5·20
	5·4630	8·0995	0·2847	5·21

ence is obtained on the oil G, which has a carbon residue of 0·31 per cent., whilst there is very little effect produced on the results obtained on oil J of 5·2 per cent. carbon residue. The results indicate that if the weight of oil taken lies within the limits of 3·75 to 4·25 grm., as laid down in the Standard Method, duplicate results should agree closely, other things being equal.

(5) *Variations in the dimensions of the Coking Bulbs.*—Table 4 gives the results obtained on oils A and N using bulbs of varying dimensions. The bulbs used on oil N represented those of maximum

and minimum external diameter of the bulb contained in a gross box. The bulb of largest external diameter was a very close

TABLE 4.

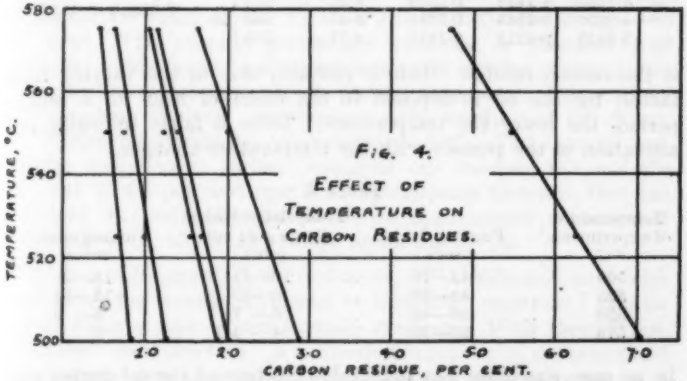
Variations in dimensions of Coking Bulbs.

(Temperature 550° C.)

Oil.	Weight of oil taken.	Weight of coking bulb empty.	Weight of carbon residue.	Per cent. carbon residue.	Outside diameter of bulb.	Wall thickness of bulb.	Wall thickness of base of bulb.	Internal diameter of capillary.
	Grs.	Grs.	Gr.		in.	Mm.	Mm.	Mm.
A. . .	3·8637	5·2203	0·0207	0·536	—	0·7	0·6	—
	3·7990	8·0475	0·0200	0·527	—	1·18	0·65	—
N. . .	3·8715	9·0495	0·0300	0·77	0·969	1·30	0·66	1·9
	4·0543	9·2707	0·0310	0·76	0·960	1·38	0·65	1·8
	3·9400	8·6287	0·0303	0·77	0·937	1·36	0·73	1·6
	4·1328	8·3442	0·0325	0·79	0·913	1·31	0·57	1·4

sliding fit in the sheaths and that of least diameter gave the impression of being a slack fit. This variation did not appear to affect the result.

The two bulbs used on oil A are described on account of the wide difference in the wall thickness of the bulb. The only effect which this variation has, is on the period elapsing between the introduction of the bulb and the commencement of fuming. This would appear to be due to the varying rate of heat transfer through the walls of varying thickness. The effect on the results is, however, negligible.



Reading from left to right, the curves are for Oils A.K.L.M.E.F. in Table 5.

(6) *Temperature Variation.*—Table 5 and Fig. 4 give results obtained on six oils, A, K, L, M, E, F, at four temperatures 500° C, 525° C, 550° C and 575° C (as indicated on the instrument used). It will be seen that the lower the temperature the higher

TABLE 5.

TEMPERATURE VARIATION.

Oil	Weight of oil taken grs.	Weight of bulb empty. grs.	Weight of carbon residue. gr.	Per cent. of carbon residue.	Temperature of Test. °C.	Variation in result per 1°C.	Percentage variation on result per 1° C.
A.	4·0000	7·9200	0·0323	0·81	500		
	3·9127	8·0517	0·0254	0·65	525	0·031	0·973
	3·7990	8·0475	0·0199	0·52	550		
	3·9950	9·5970	0·0173	0·43	575		
K.	3·9755	9·9345	0·0485	1·22	500		
	4·1000	8·7543	0·0398	0·97	525	0·0165	1·07
	3·9917	9·1295	0·0290	0·73	550		
	4·0107	8·8983	0·0252	0·63	575		
L.	4·0082	7·8878	0·0754	1·87	500		
	3·9980	8·3185	0·0612	1·53	525	0·0117	0·89
	4·0036	10·2783	0·0490	1·21	550		
	4·1350	8·2880	0·0437	1·06	575		
M.	4·0100	8·5230	0·0802	2·0	500		
	3·9782	8·1629	0·0668	1·68	525	0·0108	0·85
	3·9200	9·5607	0·0540	1·37	550		
	4·0238	8·7862	0·0453	1·12	575		
E.	4·1095	9·0620	0·1175	2·86	500		
	4·0110	7·9902	0·0970	2·42	525	0·00786	0·83
	4·0140	7·8375	0·0800	1·99	550		
	3·8770	9·4430	0·0627	1·62	575		
F.	4·0680	8·2245	0·2865	7·04	500		
	4·1290	8·3416	0·2568	6·22	525	0·00506	0·57
	4·0690	8·4245	0·2281	5·45	550		
	3·9837	9·0313	0·1877	4·71	575		

is the carbon residue. This is probably due to the varying time factor, for the oil is exposed to the effect of heat for a longer period, the lower the temperature. Table 6 fairly indicates the alteration of the periods with the temperature changes.

TABLE 6.

Temperature of experiment. °C.	Fuming starts. secs.	Time elapsed when flame goes out. mins.	Fuming ceases. mins.
500	45—70	10—11	18—20
525	40—50	8—10	12—14
550	30—40	6— 7	6— 9
575	25—30	4— 4·5	5

In no case was there any detectable ejection of the oil during any of the tests, so that one cannot assume that the results obtained

at the higher temperatures were due to the ejection of oil during the more vigorous burning period.

Fig. 4 indicates that the carbon residues of an oil at different temperatures from 500 to 575° C lie approximately on a straight line. There is a possibility that these curves are slightly incorrect, though the figures on which they are based are relative within very small limits. The error which can come into play here, is an outcome of the use of a thin iron sheath around the thermocouple. The pyrometer also cannot be immersed to more than 3 inches, if one closely adheres to the wording of the Standard Method. It is open to doubt whether a sheathed pyrometer accurately measures the temperature of the molten metal adjacent to the "hot junction" when it is immersed only to a depth of 3 inches in a "stagnant" molten metal bath. The doubt becomes more positive in the case of a bimetallic element, protected with an iron sheath, because the latter is probably conducting heat away from the hot junction. It is difficult, however, to state the magnitude of this error. In the case of the above figures, and curve, the difference between the observed and actual temperatures would be constant, and for ordinary practical purposes, they can be considered to be relatively correct within close limits.

Because of these influences being possible, determinations were made over the somewhat wide range of 500 to 575° C., in order to arrive at a "temperature coefficient" for a ± 5° C. error in temperature measurement.

Reference to Table 5 indicates that for oils A, K, L, M and E whose carbon values at 550° C. vary from 0·3 to 2·0 per cent., the variations in the results per 1° C. expressed as a percentage of the carbon value at 550° C. are 0·973, 1·07, 0·89, 0·85 and 0·83 per cent. The average percentage variation is therefore 0·92 per cent. This figure is of value because it enables one to arrive at a permissible tolerance in the carbon value when estimated by the Standard Method. According to the wording of the latter the Pyrometer should be accurate to ± 5° C. The average percentage variation in carbon values of oils between 0·3 and 2·0 per cent. is 4·6 per cent. per 5° C. It appears therefore that the Standard Method indirectly allows an approximate tolerance of ± 4·6 per cent., about an average figure for the oil.

(7) *Zero Adjustment of the Indicators.*—The indicator used with pyrometers has a scale calibrated so that the "edgewise" pointer moves along a scale of temperature readings. With these types, and if the "cold junction" is not buried in the earth, or maintained at a constant zero in a dewar flask containing an ice mixture, it is essential each day to detach one lead at the indicator and adjust

the pointer so that it records the temperature surrounding the indicator. Indicators having a range 0° to 800° C. have readings at the lower end of the scale which are very close to each other. Unless great care is taken when the zero adjustment is made, another error is introduced.

(8) *Weighing Errors.*—Taking an oil of 0·1 per cent. carbon residue and assuming one takes 4 grams. for the experiment, the weight of carbon obtained would be 4 milligrams. If the bulb containing the oil was weighed to within ± 0·01 gram., the error introduced would amount to 0·25 per cent. on the result, *i.e.*, the carbon residue would lie between the limits 0·10025 and 0·09975 per cent. Under similar conditions an oil or carbon residue 2·0 per cent. would give results between 1·995 and 2·005 per cent.

The oil may therefore be weighed to the nearest 0·01 gram.

If the sensitivity of the balance is of the order of $\frac{1}{4}$th of a milligram, the error introduced would amount to 5 per cent. of the result on an oil of 0·1 per cent. carbon residue. The error would, however, decrease as the carbon residue increases, *i.e.*, for an oil of 2 per cent. Carbon Residue the error thus introduced would be 0·25 per cent. Therefore, it is advisable to weigh the empty coking bulb, and the coking bulb containing the carbon residue to the nearest $\frac{1}{10}$th of a milligram when oils of low carbon residue are being tested.

The Applicability of the method to Cylinder Oils and Heavy Fuel Oils.

The Standard Method for Carbon Residue (Ramsbottom) for Lubricating Oils appears under the title of I.P.T. Serial Designation —L.O. 9a which reads as follows :—" The apparatus and method shall be as laid down under G.O. 9a except that for cylinder oils the quantity of the sample shall not exceed 2 grams. and the test shall be rejected if there is evidence of the oil having frothed or escaped from the bulb."

The difference between the two methods G.O. 9a and L.O. 9a lies in the limitation of the weight of oil taken, to a maximum of 2 grams. in the latter. There does not appear to be any obvious reason for this restriction and it appears that it would have been preferable to have standardised throughout on a weight of oil of 3·75—4·25 grams. In support of this contention, one would draw attention to the fact that oils C, D, E, H and I are Filtered Cylinder Oils having viscosities of more than 140 Redwood seconds at 200° F. Oils F. and J. are Dark Cylinder Oils of the " Steam Cylinder " type. Reference to Table 3 in which Carbon Residues are reported on different weights of oil will show that there is no difficulty attached to the using of as much as 5·5 grams of oil, provided that the oil is dry.

The Standard Method for Carbon Residue (Conradson) on Fuel Oils (other than intermediate oils Class VI) appears under the title of I.P.T. Serial Designation F.O.9a and contains the following statement :—

"The use of the Ramsbottom method is not recommended for residue oils." To test the validity of this statement, several experiments were carried out on a Heavy Residual Fuel Oil having a viscosity of several thousands of seconds, Redwood, at 100° F. The oil which was at hand for this work contained 0·4 per cent. of water. A quantity was warmed up to about 180° F. and blown gently with air to remove the water. The sample finally gave no indication of water in the Dean and Stark apparatus and only gave faint suspicions of a crackle when poured on to a hot iron plate. Experiments were carried out on the wet and dry Heavy Fuel Oil and the results are listed in Table 7.

TABLE 7.

EXPERIMENTS ON HEAVY RESIDUAL FUEL OIL.

(Temperature 550 °C.)

Oil.	Coking Bulb No.	Weight of Oil taken.	Weight of bulb empty.	Weight of carbon residue.	Percentage carbon residue.	Internal diameter of capillary.
		grs.	grs.	grs.		mms.
Wet	— 1	5·3557	8·2568	0·2800	5·22	1·9
	— 2	3·9688	8·1722	0·3258	8·21	1·9
	— 3	3·8422	8·4408	0·3602	9·37	2·2
	— 4	2·4148	9·2467	0·2403	9·95	1·8
	— 5	2·3307	8·3693	0·2317	9·94	2·5
	— 6	1·4375	8·1844	0·1445	10·05	2·1
Dry	— 7	5·5385	9·6540	0·3130	5·65	1·6
	— 8	3·9935	8·2970	0·3310	8·28	1·8
	— 9	3·9090	8·9410	0·3395	8·68	2·2
	—10	2·3520	7·9965	0·2385	10·01	1·85
	—11	2·4443	9·1067	0·2458	10·05	1·6
	—12	1·4465	8·2145	0·1480	10·23	2·3

It will be seen that as the weight of Fuel Oil taken is decreased from 5·5 to 2·5 grams. the result increases, and that good duplicates can be obtained when using about 2·5 grams. The carbon residue increases slightly when 1·5 gram. of Fuel Oil is used. It was noted that crackling and the evolution of steam and oil spray were emitted from coking bulbs 1 and 2 and oil spray only out of 3, 7, 8 and 9, and this persisted for about 3 minutes. In the cases of 2, 7 and 8, the capillaries must have been "coked up," for after about 4 minutes each one blew out suddenly. In the case of No. 8, a piece of carbon residue weighing 0·012 gram. was ejected. These features explain the low results obtained when using 5·5 to 4 grams. of Fuel Oil.

It will also be noted that the results obtained on the wet fuel oil are lower than the corresponding results on the dry oil.

It appears therefore that the Ramsbottom Carbon Residue method is applicable to Heavy Residual Fuel Oils provided that not more than 2 grams. of *dry* oil are employed.

Main Conclusions.

The Ramsbottom Method, in its present state, is superior to the Conradson Method for several reasons.

(1) All the most important variables which enter into such a test are controllable.

(2) By having several sheaths in the one bath of molten metal, several estimations may be carried out simultaneously. Of more importance, perhaps, is the fact that one can always include in a set of tests, a standard oil for the purpose of checking the uniform working of the apparatus.

(3) Operators in the one laboratory can agree with each other within close limits, if the same oils are tested on the same apparatus.

(4) Different laboratories testing the same oil should agree within much less than the 10 per cent. tolerance, about an average allowed by the Standard Conradson Method.

(5) Having determined carefully the carbon residues of oils used for blending purposes, the carbon residue of a blend may be calculated, given the proportions.

The objections which can be raised against the Ramsbottom Method would include :—

(1) The initial high cost of the apparatus including the pyrometer and indicator.

(2) Where only one or two carbon residues are done per day, the tests could be done by the Conradson Method in the time taken for the Ramsbottom Apparatus to warm up to 550° C.

Both of these objections would be raised by the smaller laboratories. They are not serious contentions, however, because any laboratory would choose the Ramsbottom Method unhesitatingly if it seriously desired to obtain results which could be reproduced at intervals, within small limits of accuracy.

Improvements Desired.

(1) *Uniformity of Temperature* throughout the molten metal bath is necessary and this can only be obtained by providing efficient circulation (stirring).

(2) *Accurate Temperature Measurement.*—The Standard I.P.T. method for Ramsbottom Carbon Residue allows the use of a pyrometer which is accurate to ± 5° C. It has been indicated that a difference of 5° C. in the temperature employed leads to a difference of approximately 4·6 per cent. in the carbon residue. A laboratory using a pyrometer reading 5° C. low could not expect to get results agreeing within less than approximately 9 per cent. with a laboratory using a pyrometer reading 5° C. high. Whilst the tolerance of approximately ± 4·6 per cent. is half that allowed in the Standard Conradson Method, it does not represent the minimum obtainable. An instrument for measuring the temperature of the molten metal bath within ± 2° C. should be sought.

It might be contended that if the form of pyrometer were rigorously standardized, the difficulty might be overcome. In any case, the pyrometers would need careful calibration by some central and reputable authority. Having this in mind, the National Physical Laboratory was approached, and the following was the reply :*

(1) " It is doubtful whether the wires of a base metal couple would be sufficiently homogeneous to permit of such accuracy (± 2°C.). In issuing a report on a base metal couple (without indicator) it is our practice to give the open circuit E.M.F. to an accuracy corresponding to the nearest 5°C. (usually to the nearest 0·2 millivolt) which is just outside the limit (± 2° C.).

(2) " When an indicator is used, additional sources of error are introduced. The effect of circuit resistance must be taken into account, as must also the temperature coefficient of the indicator ; if the instrument contains a copper coil which contributes an appreciable part of the total resistance, this effect may produce serious errors. There is also, of course, the possibility of slight changes in the indicator calibration due to variations in pivot friction and similar causes which will vary considerably according to the type of indicator. In consequence of these added possibilities of error, we are unable to give figures on a base metal couple with indicator to better than the nearest 10° C.

(3) " With such small immersion (3 in.) an iron sheath, unless less than 1 cm. external diameter, would lower the indications of the thermocouple by conduction to an extent which would certainly be appreciable when an accuracy of ± 2° C. is being sought.

" In the event of the use of a thermocouple for this work, we think it would be highly desirable to use a fused silica sheath, and

* Published by kind permission of the Director, National Physical Laboratory.

it would certainly be necessary to measure the E.M.F.'s with a potentiometer. A thermocouple of platinum, platinum 10 per cent. rhodium, would, in these circumstances, yield higher accuracy than one of base metal.

" The following methods might also be considered :—

(a) " Platinum resistance thermometer. This would preferably be of the laboratory 4 lead compensated type in silica sheath, and used with the Whipple indicator.

(b) " Mercury in steel, dial indicating thermometer. With this type of instrument, it would be necessary to have the full 3¼ in. of the capillary immersed, but perhaps it would be possible, since the capillary is flexible, to mount the bulb in a horizontal position. The bulb would probably be about 3 in. long.

"The following table summarises the methods available for measuring temperatures of about 550° C. together with the accuracy to which we could give figures in each case :

Method.	Type.	Figures given to nearest
Thermocouple ..	Rare metal (to be used with potentiometer) ..	2° C.
	Base metal (to be used with potentiometer) ..	5° C.
	Rare or base metal with indicator	10° C.
Platinum resistance thermometer	Four lead type with Whipple indicator ..	1° C.
	Two lead high resistance type with deflection indicator	5° C.
Mercury in steel thermometer	Dial indicating	2° C."

It appears therefore that unless one goes to great expense, a thermocouple with a guaranteed calibration cannot be used for measuring temperatures of a Ramsbottom apparatus within less than ± 5° C. The information that a mercury in steel thermometer of the dial indicating type can be standardised to within 2° C. (± 1° C.) is of much interest. Such an instrument has several advantageous features, other than the one already mentioned.

(1) It is exceedingly robust.

(2) It can be obtained at as moderate a price as that of a base metal thermocouple with indicator.

(3) It needs no " zero adjustment."

The only difficulty attached to the use of such a thermometer is that it is working near to its maximum limit, and care would have to be taken to ensure its not being heated beyond about 580° C. for a very long period.

In view of the foregoing, experiments have been set on foot to compare results obtained on a range of oils, using (1) a stagnant molten metal bath ; (2) a vigorously agitated metal bath, in each case comparing (a) a base metal thermocouple with indicator ; (b) a platinum resistance thermometer ; (c) a mercury in steel thermometer of the dial indicating type.

The author desires to express his thanks to the Anglo-American Oil Co. Ltd. for permission to publish the above data.

Recent Advances in our Knowledge of Natural Gas and "Cracking" Gas and their Industrial Utilisation.*

By H. M. Stanley, M.Sc. (Student Member).

Part I.—Natural Gas.

In the industrial and commercial world, the term "natural gas" is used to designate all those hydrocarbon-containing gases which are associated either directly or indirectly with crude petroleum

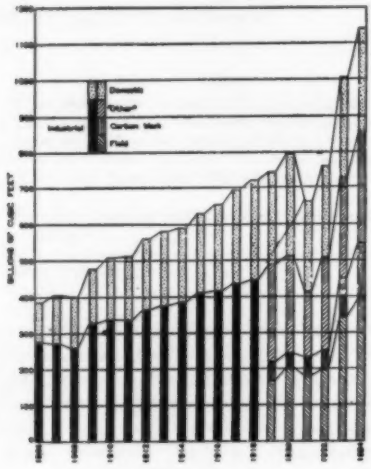


Fig. 1.

UTILISATION OF NATURAL GAS IN U.S.A., 1906-1924.

Reproduced from "Mineral Resources of the United States, 1924," Part II., p. 322.

and also to a much smaller extent with certain bituminous shale deposits.[1] It is convenient to mention here, in passing, two other types of naturally occurring hydrocarbon-containing gases, namely :

* Paper received June 15, 1929. Awarded Student's Medal and Prize, 1928–29.

(1) gases derived from coal measures, and (2) gases associated with, and probably derived from, igneous rocks. Both these two latter types are of little interest compared with the former class, which constitutes by far the most important type industrially.

Natural gas invariably accompanies oil in the strata, though the converse is not always the case. Indeed, the majority of gas wells do not yield oil. In the latter case, however, the gas has probably migrated from its original horizon. Natural gas occurs in enormous quantities in many parts of the world where oil is found—in Russia, Poland, Hungary, Rumania, Burma, Persia, Mexico, S. America, but more especially in the U.S.A. and Canada. The industrial utilisation of this gas has assumed greatest proportions in the U.S.A. Some idea of the magnitude of production and utilisation in that country during the period 1906-1924 can be obtained from an inspection of the accompanying diagram, Fig. 1.

Thus, for example, in 1924, in the U.S.A., no less than 1,141,000,000,000 cu. ft. of natural gas were consumed, while in the last few years this enormous figure has been greatly surpassed.

Waste and Conservation.—In the early days of the industry the gas invariably accompanying the oil was regarded as an objectionable by-product to be disposed of as rapidly as possible. This resulted in a great and often deliberate waste of this valuable supply of fuel in the U.S.A. and elsewhere, but steps are now being taken to conserve resources. Unfortunately it is not feasible to store large quantities of gas under pressure in artificial containers, and, owing to the fact that producing wells are often situated in districts remote from points of possible industrial and domestic utilisation, great quantities of gas are still being wasted or used in an inefficient manner. The difficulty of transporting natural gas to its place of utilisation has been overcome in some parts of the U.S.A. by the construction of large high pressure pipe-lines, but the expense involved in the construction of these is very great, and a very large and constant supply of gas must be assured before such pipe-lines can economically be laid down.

Composition of Natural Gas.—The researches of Burrell and his collaborators have shown that the chief constituents of American natural gas are the paraffin hydrocarbons, methane, ethane, propane, butane, etc. Natural gas containing considerable amounts of higher paraffin hydrocarbons up to octane (as a result of its association with crude petroleum) is known as " wet " gas, while the so-called " dry " gas consists of the lower members of the series only and, in particular, of methane. Table 1 gives a list of these hydrocarbons from methane to octane, and shows the rise of boiling point with increase of molecular weight :—

TABLE 1.

	Name.	Formula.	B.P. °C.	Crit. temp.	Calorific value. B.Th.U./cu. ft.
	Methane	CH_4	-160	-81·8	1,008·5
	Ethane	C_2H_6	-89·3	35	1,763·2
	Propane	C_3H_8	-44·1	97	2,518·0
Normal	Butane	C_4H_{10}	-0·3	153	3,273·0
,,	Pentane	C_5H_{12}	36·4	197	4,027·0
,,	Hexane	C_6H_{14}	69·0	234·8	4,782·0
,,	Heptane	C_7H_{16}	98·4	—	5,537·0
,,	Octane	C_8H_{18}	125·5	—	6,291·0

Besides the paraffin hydrocarbons other gases may be present, such as carbon dioxide, sulphuretted hydrogen, nitrogen and helium (up to 1·8 per cent.), but Burrell found a notable absence of carbon monoxide, hydrogen and acetylenic and olefinic hydrocarbons. It is very probable that cyclo-paraffins and benzene vapour are present in some natural gases.[3] Table 2 gives the composition of some natural gases of various types:—

TABLE 2.

Country.	Locality.	CH_4	C_2H_6*	N_2	CO_2	H_2S	He
U.S.A.	(1) Pittsburg, Pa. (City Gas)	84·7	13·7	1·6	—	—	—
	(2) Los Angeles, Calif. ..	77·5	16·0	—	6·5	—	—
	(3) Fort Smith, Ark. ..	99·2	—	0·6	0·2	—	—
	(4) De Soto, La.	97·3	—	2·3	0·4	—	—
	(5) Glasgow, Ky.	23·6	69·7	3·8	—	2·9	—
	(6) Dexter, Ka.	14·9	0·4	82·7	—	—	1·84
	(7) Mc.Kittrick, Calif. ..	66·2	1·0	2·4	30·4	—	—
Canada	(1) Simcoe, Ontario ..	80·3	7·6	11·8	0·3	—	—
	(2) Medicine Hat, Alberta	90·0	3·0	5·0	0·8	—	—
	(3) Turner Valley, Alberta	71·8	25·9	6·9	2·1	—	—
Persia	(1) High pressure gas ..	81·0	16·0	1·4	0·7	1·0	—
	(2) Low pressure gas ..	36·0	52·6	1·7	1·9	7·8	—

(* and higher hydrocarbons.)

Analysis of Natural Gas.—The ordinary methods of gas analysis are not readily applicable to the examination of natural gas, and during the last few years considerable advance has been made in this direction, largely due to the pioneer work of Burrell of the U.S. Bureau of Mines. Ordinary methods of analysis furnish the actual percentage of all the paraffin hydrocarbons in the gas, and also give a mean value of "n" in the formula (C_nH_{2n+2}). If only two paraffin hydrocarbons were present, it would be possible to calculate the actual percentage of each constituent from this data. Unfortunately, natural gas is usually composed of at least three paraffin hydrocarbons, and for such a mixture new methods of analysis must be applied.

The importance of the fundamental analysis of gaseous mixtures not only in research problems, but also in the control of plant operations and in the assessing of plant efficiency has been justly pointed out by Podbielniak.

These methods of separation of the individual paraffin hydrocarbons may be divided into two classes, namely :—

1. Methods in which the mixture of gaseous hydrocarbons is liquefied at the temperature of liquid air, and the liquid so obtained

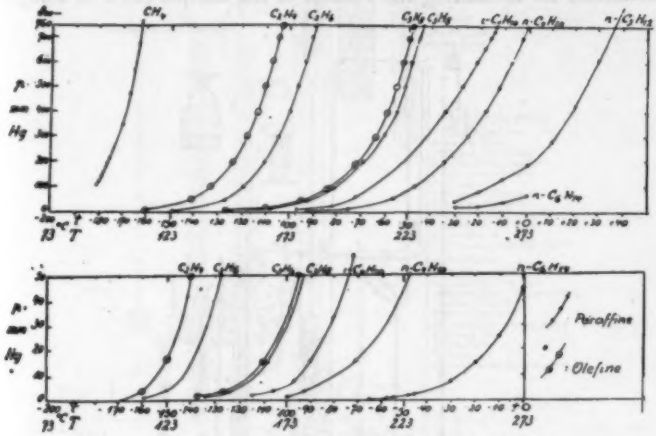


FIG. 2.

VARIATION OF VAPOUR PRESSURES OF PARAFFIN AND OLEFINE HYDROCARBONS WITH TEMPERATURE.

Reproduced from "Brennstoff-Chemie," 1925, **6**, 172.

fractionated at low temperatures to give individual members of the series.

2. Methods in which the mixture of gaseous hydrocarbons is subjected to a process of fractional condensation at low pressure and in various temperature stages.

Both these systems of working are dependent upon the fact that for any particular temperature, the vapour pressures of the lower members of the paraffin series lie much further apart from one another than is the case with higher members of the same series. Thus, if we inspect the curves[4] (Fig. 2) of the variation of the b.pt. of the lower paraffin and olefine hydrocarbons with pressure, we find that the lower member of the series possesses a

considerable vapour pressure at a temperature at which the next higher homologue still shows no perceptible pressure.

Considering methods of analysis involving fractionation processes, the apparatus of Burrell, Seibert, and Robertson[5] will be first discussed since the work of these authors resulted for the first time in the separation of the individual hydrocarbons present in natural gas. Their apparatus (Fig. 3) consisted essentially of a Tœpler pump, a liquefying bulb (*b*) a gas analysis burette (*d*) and a gas container for measuring the volume of the sample prior to analysis.

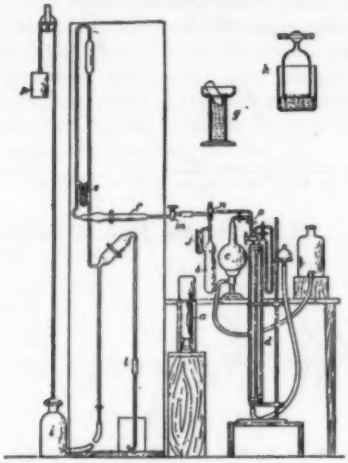


FIG. 3.

BURRELL-SEIBERT APPARATUS.

Reproduced from U. S. Bureau of Mines Technical Paper 104, *p.* 10.

The gas sample is measured in (*c*), then transferred to the burette (*d*), and passed into the liquefying bulb (*b*), cooled in liquid air. The process then consists of treating the liquefied mixture of hydrocarbons in the following manner :—

1. The uncondensed gas and most of the methane is removed by means of a Tœpler pump. The residue is vaporised and again liquefied at the temperature of liquid air. More methane is then pumped away by the pump, this sequence of operations being repeated until no more methane is available, and the system is under high vacuum. At the temperature of liquid air, ethane has a negligible vapour pressure.

2. Having removed the methane, the temperature of the residual mixture is raised to –140° C., and then slowly to –125° C., and the resulting gas pumped away by means of the Tœpler pump. The distillate thus obtained is again treated in the same way, the final

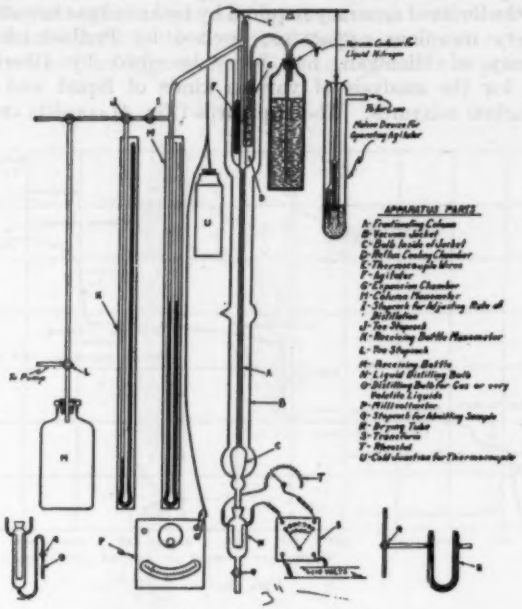


FIG. 4.

APPARATUS FOR ANALYSIS OF HYDROCARBON MIXTURES BY FRACTIONATION AT LOW TEMPERATURES.

Reproduced from "Oil and Gas J.," October 18, 1928, *p.* 142.

separation of the ethane from accompanying propane being accomplished at –155° to –140° C.

3. Propane is separated from the butanes at –135° to –120° C.

4. The residual liquid, consisting of butane and higher hydrocarbons, is vaporised, pumped away and analysed.

The work of Burrell and his collaborators represents a great advance in the known methods of examining natural gas. Unfortunately the process is somewhat laborious and the time required considerable so that this method is useless for plant control

purposes. Shepherd and Porter[7] have devised an apparatus, which is more convenient and reduces very substantially the time required for one analysis. The mode of procedure and general principles involved are similar to those employed by Burrell. The errors of the analysis are of the order of 0·1 per cent., which easily falls within the limits of accuracy required by technical gas investigations.

A very ingenious apparatus, devised by Podbielniak at the University of Michigan, has been described by Oberfell and Alden[8] for the analysis of various kinds of liquid and gaseous hydrocarbon mixtures. The apparatus (Fig. 4) consists essentially

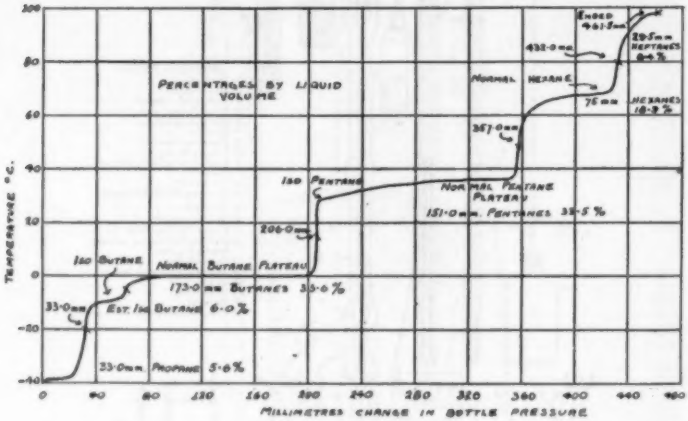


FIG. 5.

DISTILLATION CURVE OF NATURAL GASOLINE.

Reproduced from "Oil and Gas J.," October 18, 1928, p. 142.

of a very efficient fractionating column and still, adapted to precise manipulation on small amounts of sample, and operating at low temperatures. Heat input is provided, when necessary, in the distilling bulb, and reflux cooling is obtained by the evaporation of liquid nitrogen in a pentane bath surrounding the top of the column. The temperature of the distillate vapours is measured by means of a thermo-couple in the still-head, and there is an ingenious device for agitating the cooling liquid. The pressure in the still-head is maintained usually at atmospheric pressure, the vapours being conducted into an evacuated receiver of known volume. Vapour volume passing into this container is measured by fall in pressure (indicated by manometer K), using ideal gas

laws and known physical constants for calculating gas or liquid volumes at standard conditions.

This apparatus has a wide working range of temperature and pressure, and is applicable to the analysis of natural gasoline and gas mixtures of various kinds. For example, propane and butane can be distilled off at atmospheric pressure with very sharp breaks. The results obtained in the analytical distillation of natural gasoline are represented in Fig. 5, in which the plateaux represent the

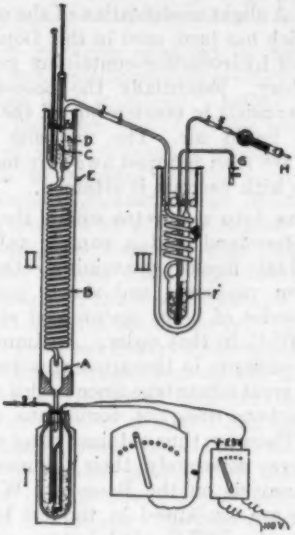


FIG. 6.

DAVIS FRACTIONATING COLUMN.

Reproduced from "Ind. Eng. Chem.," Analytical Edition, 1929, **1**, 63.

distillation of individual compounds, while the sudden breaks in the curve occur when the whole of one compound has distilled over.

This apparatus has recently been greatly modified and improved in various ways by Podbielniak.[9] The fractional distillation is accomplished in a long Pyrex column of small bore (about 4·5 mm. internal diameter), integral with the distilling bulb and reflux cooling chamber, surrounded by a vacuum jacket which is silvered to improve thermal insulation. The silver is so deposited, however, that the packing and refluxing liquid in the column are clearly visible to the operator.

Quite recently, Davis[10] has devised a similar fractionating tower (see Fig. 6) for the sharp fractionation of gaseous mixtures, which consists of 3 to 5 metres of 5 mm. glass tubing bent into a spiral of 30 to 40 turns with a low pitch, surrounded by a glass jacket, highly evacuated and silvered like a Dewar flask to ensure thermal insulation. Turning now to analytical processes involving fractional condensation, the apparatus and methods devised by Tropsch and Dittrich[4] are of great interest. The method of analysis is simpel and the apparatus employed, which is represented in Figs. 7 and 8, easily manipulated. A slight modification of the original apparatus of Tropsch and Dittrich has been used in this Department for some time for the analysis of hydrocarbon-containing gases and has been found very satisfactory. Essentially the procedure, when conducting an analysis, consists in condensing all the hydrocarbons at the temperature of liquid air. The methane as well as the uncondensable gases are then pumped away by means of a Toepler pump (Fig. 7) until a high vacuum is attained.

This pump delivers into a burette where the volume of each fraction may be determined and a sample taken for ordinary analysis. The residual liquid, containing ethane and higher hydrocarbons, is then vaporised and slowly passed, under high vacuum, through a series of bulbs maintained at temperatures of −90°, −120° and −180° C. in that order. An immediate condensation occurs and the pressure in the apparatus remains practically nil, a fact which is of great advantage since in this way the solubility ratio of the hydrocarbons does not come into operation to any appreciable extent. There are thus obtained three separate fractions, which are pumped away separately, their volumes determined, and samples taken for analysis on the Bone and Wheeler apparatus. Ethane and propane are condensed in the last bulb (at −180° C.), cropane and butane at −120° C., and butane and higher hydroparbons at −90° C. If olefines are present, these are found with the corresponding paraffins.

Present Methods of Utilisation.—The efficient utilisation of natural gas is one of the most important problems confronting the petroleum industry. The reckless waste of this valuable source of energy, which has occurred in the past and still occurs to some extent even at the present day, must be stopped and every effort made to conserve resources. It is proposed to consider very briefly the uses of natural gas, and, later, to indicate the ways in which the problem of the better utilisation of this material is being attacked.

" Wet " gas, *i.e.*, gas containing amounts of higher hydrocarbons which are liquid under normal conditions, is used as a source of natural gasoline. The application of natural gasoline to the

petroleum industry has resulted in a 15 per cent. increase in the production of motor spirit. Natural gasoline supplies readily volatile components to motor-spirit fractions, and when blended with heavy naphtha yields a mixture comparable with the straight-run product. The removal of gasoline from natural gas is effected by means of three distinct methods, which are :—

1. Compression.
2. Absorption by means of oil.
3. Adsorption by means of adsorbents such as activated charcoal.

The properties of gasolines prepared by these processes differ to some extent, the compression process giving rise to a very volatile product which must be " stabilised " before it can be blended. After the gasoline has been removed, the stripped gas may be used in a variety of ways, depending on the conditions. Where the producing wells are situated close to large industrial centres, the stripped gas finds application as an industrial and domestic fuel. Enormous quantities of gas are utilised in this way in the U.S.A. It is unfortunate, however, that there are many gas fields which are too remote from large fuel-consuming centres. As pointed out previously, the construction of large high-pressure pipe-lines has helped to solve the difficulty.

Where the gas is produced in very isolated fields in the U.S.A., it is usually burned with an insufficient supply of air, so as to yield carbon black, a very finely-divided flocculent form of carbon used largely in the manufacture of printer's ink, gramophone records, black paint and enamel, stove polish, and as a filler for rubber goods. The yield of carbon produced by this incomplete combustion is very low, usually about 2 per cent. of the theoretical, and on this account the industry has been condemned as wasteful. It must be confessed, however, that the industry absorbs gas derived from very isolated fields where an industrial or domestic utilisation is impossible, and at the same time furnishes a product, the properties of which cannot be successfully imitated by carbon, manufactured by other processes, such as thermal decomposition.[11]

Natural Gas as Fuel.—Natural gas constitutes a very valuable, clean fuel for domestic and industrial purposes. The calorific values, expressed in B.Th.U. per cubic foot gross, of the individual hydrocarbon constitutents are tabulated below :—

Hydrocarbon.	Gross calorific value. B.Th.U. per cu. ft.
Methane	1,009
Ethane	1,764
Propane	2,519
N-butane	3,274

The calorific value of natural gas depends, of course, upon its composition, a figure of about 1,000 B.Th.U. being a good average value. It should be noted that this is about twice the calorific value of ordinary coal gas. Owing to the fact that natural gas requires considerably more air for complete combustion than lower grade fuels, such as water gas and coal gas, the efficiency of heating will be greater in the case of the latter, because each cubic foot of their products of combustion has more heat to give up than in the case of natural gas. On the other hand, the amount of manufactured gas required for a given amount of work will be greater.

In the U.S.A. it has become recognised that the domestic consumer has an incontestable right to demand preference over industrial users in the matter of natural gas supply. When the demands of these domestic consumers have been satisfied,the remaining supply of gas should be used in certain high-grade industries. Three of the largest industrial consumers of natural gas in the U.S.A. are zinc smelters, brick plants, and glass factories. For most industrial purposes natural gas is used not merely as a replacement of coal or coke fuel, but because it permits close heat regulation and is preferable as a fuel when high quality of product is important, since it exerts no contaminating influence.

It is now generally conceded that the most efficient method of using natural gas as a fuel is as an enricher in manufactured gas. Enrichment with natural gas is easily carried out and results in an economical utilisation.[12]

Recent Advances in Natural Gas Utilisation.—(1) In the last few years a very interesting development has taken place in the U.S.A., which is likely to have far-reaching effects. This is the production of large quantities of the so-called liquefied petroleum gases, consisting largely of propane and butanes. These substances, which are gaseous under normal conditions, but liquid under pressure, are obtained by topping natural gasoline under considerable pressure, a process resulting in a stabilisation of the natural gasoline. The liquefied petroleum gas is usually purified from sulphuretted hydrogen, and stored in large tanks under pressures of more than 100 lbs./sq. in. The liquefied gas is transported in steel cylinders or in special tank cars. The following are a few of the uses to which these valuable materials may be put :—

(*a*) As a domestic fuel in districts remote from towns.
(*b*) As industrial fuel in certain high-grade industries.
(*c*) As an enricher or carburetting agent for manufactured gas and water gas.
(*d*) As a substitute for acetylene in welding operations.
(*e*) As commercial solvents and refrigerants, and as raw materials for chemical industry.

The available supply of these materials is very great and it has been calculated that the natural gasoline industry of U.S.A. might easily produce 5,000,000 gallons of propane and 3,500,000 gallons of butane daily, without appreciable diminution of natural gasoline supply.[13]

We have recently examined in our laboratories, a sample of a liquefied petroleum gas called " Skelgas," manufactured by the Skelly Oil Co.[14] This consists of nearly pure propane with only small quantities of ethane and butanes.

(2) Another very interesting application of unwanted gas, particularly high pressure gas from compression plants, is for repressuring oil-bearing sands in which gas pressure has fallen to a low figure. This results in an increase in oil production and also in yield of gasoline.

(3) The search for better and more economical methods of producing carbon black is being prosecuted with vigour, and it is now reported that a process is in operation capable of producing 9 lb. of good quality carbon black per 1,000 cubic feet of gas. Carbons produced by the thermal decomposition of hydrocarbons at high temperatures are not apparently suitable substitutes for carbon black in most of its applications. It is reported, however, that a good carbon black may be produced by the action of the electric arc on hydrocarbon gases.[15]

(4) The discovery of the gaseous element helium in a natural gas at Dexter, Kansas, by Cady and McFarlane[16] in 1905 marks the first stage in the romantic story of scientific research on this subject, which has finally resulted in the commercial production of very large quantities of helium in the U.S.A. Helium is of value for use in balloons and airships on account of its lightness, and particularly of its non-inflammability. The U.S. Bureau of Mines erected a large plant at Fort Worth, Texas, in 1921 to treat 5,000,000 cubic feet of natural gas per day, and since that time different stages of the process have been much improved so that the cost of extraction has been reduced from £100 to less than £4 per 1,000 cubic feet of helium.

Possible Methods of Utilisation.—The paraffin hydrocarbons in natural gas appear to present to the chemist an almost inexhaustible supply of raw material for chemical manufacture, and synthesis. Recent research has opened up a vast field of possible applications for these substances, and it is evident that in the near future petroleum and natural gas will be regarded as starting materials for the manufacture of commercially valuable products other than fuels. Although strictly not within the scope of this paper, mention

must be made of the utilisation of pentane and isopentane by the Sharples Solvents Corporation as raw materials for the manufacture of a large variety of amyl alcohols and their derivatives.[17]

(1) *Carbon and Hydrogen.*—In the first place, the paraffin gases may be regarded as potential sources of vast supplies of carbon and hydrogen. Of these two elements, the carbon produced by thermal decomposition processes is of little value. On the other hand, it is well known that a good supply of cheap hydrogen is one of the primary needs of chemical industry to-day, more particularly in regard to the synthesis of ammonia and the berginisation of coal. The process employed for the resolution of these hydrocarbons into their elements is one of thermal decomposition, the gas being passed through a retort of refractory material heated to about 1,200° C. Under these conditions methane, which is the most stable of the hydrocarbons, gives twice its volume of hydrogen, according to the equation, $CH_4 \rightarrow C + 2\,H_2$.

Unfortunately, the decomposition is never quite complete even at high temperatures, and the presence of small quantities of undecomposed methane would probably exclude the use of this hydrogen for the synthesis of ammonia by the Haber-Bosch or Casale processes. For the berginisation of coal, however, where hydrogen of 85 per cent. purity is good enough, this method would be very suitable.

Probably a better method for the conversion of these hydrocarbons into hydrogen is by interaction with steam at elevated temperatures and in the presence of suitable catalysts. Under these conditions, methane gives rise to a mixture of carbon monoxide and hydrogen according to the equation,[18] $CH_4 + H_2O \rightarrow CO + 3\,H_2$.

This mixture of carbon monoxide and hydrogen might then be allowed to react with a further quantity of steam at a lower temperature and also in the presence of a catalyst to give a mixture of carbon dioxide and hydrogen thus :—[19]

$$(CO + 3\,H_2) + H_2O \rightarrow CO_2 + 4\,H_2.$$

From this gas mixture the carbon dioxide could be easily eliminated, leaving hydrogen gas in a fairly pure condition. An interesting patent of Casale [20] describes the conversion of methane into carbon monoxide and hydrogen by passing a mixture of methane, steam, and oxygen through a reaction chamber maintained at 1,100° C. to 1,300° C. According to this patent, industrial success in this reaction will only be attained when conditions in the reaction chamber are such that the concentration of methane is practically nil. These conditions are said to be realised when in the reaction chamber the system of reacting gases

(1) is maintained at pressures below atmospheric,
(2) attains a temperature of above 1,000° C., and
(3) contains a large excess of steam.

The B.A.S.F. have patented a process[21] for converting methane into carbon monoxide and hydrogen by mixing methane-containing gases with air or oxygen and allowing such mixture to react over a catalyst of nickel-coated magnesia.

The interaction of natural gas with steam might also be used to produce mixtures of carbon monoxide and hydrogen suitable for conversion into methanol by the Badische process or into liquid fuels by the Fischer process.

(2) *Chlorination.*—The chlorination of the gaseous paraffin hydrocarbons has not yet been studied exhaustively. Recent information indicates that methane may be converted to a large extent into methyl chloride exclusively under certain conditions. Methyl chloride is a substance which can be used extensively in chemical synthesis and for the production of methyl alcohol. The higher homologues of methane might similarly be converted into the corresponding alcohols by chlorination and subsequent hydrolysis, but a cheap supply of chlorine would be necessary to enable such a process to be an economic success.

(3) *Oxidation.*—The partial oxidation of the paraffin gases to products of established commercial value offers a wide field for exploitation, and the commercial oxidation of methane to formaldehyde and methanol by the Empire Refining Co. has greatly stimulated efforts along these lines[22]. In this connection, the possibility of converting propane into acetone according to the equation, $CH_3—CH_2—CH_3 \rightarrow CH_3—CO—CH_3$, a reaction appearing simple, at least on paper, is well worth investigation.

(4) *The Pyrolysis of Natural Gas.*[23]—The decomposition of the hydrocarbons ethane, propane, and the butanes, by thermal treatment has been shown to give rise to a number of valuable substances. Disregarding the case of methane which will be considered in greater detail later, the various stages in the decomposition of the above hydrocarbons may be traced as follows :—

(*a*) In the region 600°—700° C., the two main reactions are (i) dehydrogenation to the corresponding olefine, and (ii) demethanation with the production of a lower olefine. Thus propane will give rise to propylene by reaction (i) and to ethylene and methane by reaction (ii).[24]

(i) $C_3H_8 \rightarrow C_3H_6 + H_2$.
(ii) $C_3H_8 \rightarrow C_2H_4 + CH_4$.

(*b*) At higher temperatures, methane and hydrogen tend to accumulate while there is a considerable production of aromatic

hydrocarbons. In the case of ethane for example, the optimum temperature for the production of aromatic hydrocarbons is about 800° C.[25]

(*c*) Above 800° C. all hydrocarbons tend to be completely decomposed into carbon, hydrogen and methane.[26]

(*d*) The presence of active catalytic materials tends to accelerate all the above reactions and usually results in an increased production of carbon, hydrogen, and methane.

The production of olefines by the thermal dehydrogenation of the paraffin gases is of profound interest since these olefines are much more reactive than the corresponding saturated hydrocarbons and may be readily converted into alcohols, glycols, and other products of established value. It is reported, for example, that the Union Carbide and Chemical Corporation has developed a process for converting ethane into ethylene, and that this process is actually in operation.[27] The ethane is first separated from natural gas by fractional distillation and is then cracked by passage through copper, porcelain, or eathenware tubes at 600° C., when ethylene is produced. The reaction involved is $C_2H_6 \rightleftarrows C_2H_4 + H_2$, and has recently been shown to be an equilibrium process below 600°, though complicated by other reactions such as demethanation.[28] It is reported that the I.G. Farbenindustrie A.G. are interested in this process.[29] It is obvious that suitable contact materials will play an important rôle in effecting a smooth dehydrogenation of the paraffin hydrocarbons.

The cracking of butane and iso-butane is now carried out on a commercial scale for the production of a mixture of ethylene and propylene, which is used for the manufacture of the corresponding glycols.[22]

One of the most important developments in this connection is the pyrolysis of natural gas in such a way as to give aromatic hydrocarbons such as benzol, which may be blended with ordinary gasoline to give a good anti-knock fuel. Williams-Gardner found that at 800° C. ethane gave a mixture of aromatic hydrocarbons to the extent of about 15—25 per cent. and about half of this mixture was benzene and its immediate homologues. The Anglo-Persian Oil Co. have carried out some large-scale tests using two types of gases of the following compositions :—

Constituent.	Gas I.	Gas II.
H_2S	0·9	7·8
O_2+CO_2	0·7	1·9
N_2	1·4	1·7
CH_4	81·0	36·0
C_2H_6	16·0	32·0
C_3H_8	—	9·0
C_4H_{10}	—	9·0
C_5H_{12}	—	6·0

On pyrolysis, gas I gave about 220 gallons of benzol per 1,000,000 cu. ft., while gas II furnished 770 gallons for the same amount of gas, besides quantities of tar. It is evident that gases comparatively rich in hydrocarbons higher than methane, give much better yields of benzol than gases rich in methane.[30]

The Pyrolysis of Methane.—Since methane is the preponderating constituent of natural gas, the possibility of converting this hydrocarbon into valuable materials, more particularly into higher hydrocarbons by thermal treatment, is a question of outstanding importance. Until quite recently it was believed that the main, if not the only, reaction involved was the resolution of methane into its elements according to the equation :—

$$CH_4 \rightarrow C + 2H_2$$

In October of last year, however, Fisher[31] announced that under suitable condition of gas velocity and temperature, and in the absence of catalytic materials, methane could be converted into higher hydrocarbons, chiefly of an aromatic nature, to the extent of about 12-13 per cent. Fischer used tubes of porcelain and silica heated to temperatures of 900°–1100°C. The tar obtained contained naphthalene and higher aromatic hydrocarbons, while the light oil consisted of benzene and its homologues. Acetylene and olefines were detected in the gaseous products of the reaction. The results of Fischer were later substantiated by Stanley and Nash[32] and also by Wheeler and Wood[33].

The thermal decomposition of methane has been studied in this Department with a view to the production of liquid hydrocarbons capable of being used as motor fuels[34]. The results so far obtained may be briefly outlined as follows :—

(*a*) The use of comparatively long heating periods tends to cause methane to break down into its elements almost exclusively This tendency is greatly increased by the use of large heating surfaces and also by the presence of active materials such as iron and nickel.

(*b*) On the other hand, with short heating periods at temperatures of 1000°—1200° in the presence of comparatively inactive heating surfaces, methane decomposes with the production of numerous higher hydrocarbons. The gaseous products of the reaction were examined by condensation methods and found to contain, besides H_2 and unchanged CH_4, acetylene, ethylene, traces of ethane, a higher olefine with four or more carbon atoms, and benzene vapour. The light oil was mainly benzene and its homologues, while the tar contained naphthalene and other higher aromatic hydrocarbons. The percentage conversion of methane into higher hydrocarbons attains a sharp maximum at any particular temperature,

depending on the gas velocity. An increase in the temperature of the reaction leads to an increase in the gas velocity at which maximum production of higher hydrocarbons takes place. Figs. 9 and 10 show the effect of changing the gas rate on the yield of higher hydrocarbons, at 1100°C.

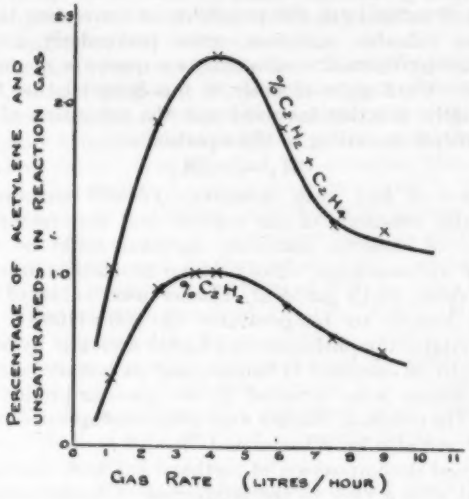


FIG. 9.

YIELDS OF ACETYLENE AND ETHYLENE FROM METHANE AT DIFFERENT GAS RATES AT 1100° C.

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As the heating duration is diminished, the formation of carbon and hydrogen by the reaction $CH_4 \rightarrow C + 2H_2$, diminishes rapidly and may become negligible. The best yields of higher hydrocarbons were obtained at a temperature of 1150° and using a heating period of 0·6 sec. only. Under these conditions, the yield of light oil was 4·8 per cent. and of tar 6·2 per cent., while the gaseous products contained 2·21 per cent. of acetylene and 1·25 per cent. of ethylene. This corresponds to a total conversion of methane into higher hydrocarbons of about 20 per cent., while the reaction $CH_4 \rightarrow C + 2H_2$ had occurred to the extent of only about 6 per cent. The light oil yield corresponded to a production of 200 gallons of benzol per 1,000,000 cu. ft. of methane. It is believed that the production of these higher hydrocarbons can be explained on the

assumption of the intermediate formation of free residues $CH_3\cdot$, $CH_2{:}$, and $CH{:}$, which can then either polymerise or be hydrogenated, or break up into carbon and hydrogen.

Hague and Wheeler[35] believe that the formation of aromatic substances from methane may be traced through free $CH_2{:}$ resi-

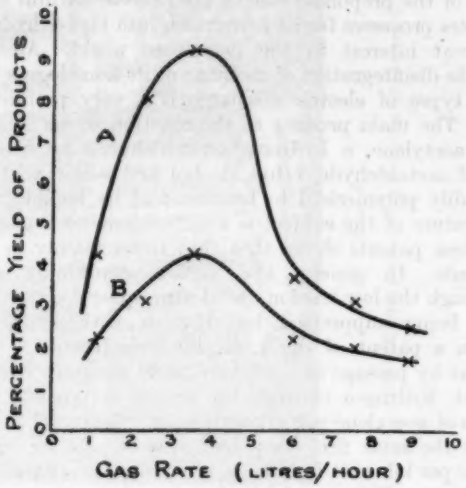


FIG. 10.

PERCENTAGE CONVERSION OF METHANE INTO LIGHT OIL AND TAR WITH VARYING GAS RATES AT 1100°. A = LIGHT OIL + TAR. B = LIGHT OIL.

Reproduced from "J. S. C. I.," 1929, 48, 5 T.

dues to ethylene, two molecules of which form butylene which loses hydrogen to form butadiene. A repetition of this process gives hexatriene which changes to benzene.

$$CH_4 \rightarrow CH_2{:} \rightarrow CH_2{:}\ CH_2 \rightarrow CH_3{-}CH_2{-}CH{=}CH_2$$
$$\rightarrow CH_2{=}CH{-}CH{=}CH_2 \rightarrow CH_3{-}CH_2{-}CH{=}CH{-}CH{=}CH_2$$
$$\rightarrow CH_2{=}CH{-}CH{=}CH{-}CH{=}CH_2 \rightarrow$$

The yields of higher hydrocarbons obtained so far by the thermal decomposition of methane are obviously too small for the process

to be of economic importance *per se*, yet it is doubtful whether optimum conditions have been attained so far. There is much need for research, particularly in the direction of the employment of more suitable heating surfaces.

Conversion of Methane by Electric Discharge.—Mention has already been made of the preponderance of methane in natural gas, a fact which renders processes for its conversion into higher hydrocarbons of very great interest to the petroleum world. Among these processes, the disintegration of methane or its homologues by means of various types of electric discharge is a very promising mode of attack. The main product of the reaction seems to be almost invariably acetylene, a hydrocarbon which can be used for the synthesis of acetaldehyde, ethyl alcohol and acetic acid, and can also be readily polymerised to benzene and its homologues. The patent literature of the subject is very voluminous, but a detailed study of these patents shows that they differ mainly in constructional details. In general the methane-containing gases are passed through the low tension arc at atmospheric pressure, carbon deposition being suppressed by dilution with hydrogen. For example, in a patent of the I. G. Farbenindustrie A.-G.[36], it is claimed that by passage of a mixture of 30 per cent. methane and 70 per cent. hydrogen through the arc, it is possible to obtain 70–80 litres of acetylene per kilowatt-hour. Krauch[29] has recently stated that the same firm have been able to produce 80–90 litres of acetylene per kilowatt-hour using a modification of the Schönherr arc ; this is an efficiency of 35–40 per cent. on the energy used, and compares very favourably with the carbide process of acetylene manufacture, in which 1 kilowatt-hour of electrical energy expenditure results in the production of 72 litres of acetylene.

Experiments carried out in this department by Nash and the Author have[27] shown that the spark discharge decomposes methane at atmospheric pressure, the main products being acetylene and hydrogen, produced according to the equation :

$$2\ CH_4 \rightarrow C_2H_2 + 3\ H_2 - 92\ \text{Cal.}$$

Ethylene is also produced in smaller quantities, as well as higher liquid and solid hydrocarbons. The liquid products are acetylenic in character and very little benzene is produced. Much more important, however, is the fact that the carbon produced in the discharge is a very finely divided flocculent form, very similar to carbon black, and the yield of this carbon may be as high as 20 per cent. of the theoretical. The electrical disintegration of gaseous hydrocarbons has been previously proposed as a method of producing carbon black by Jakowsky[15].

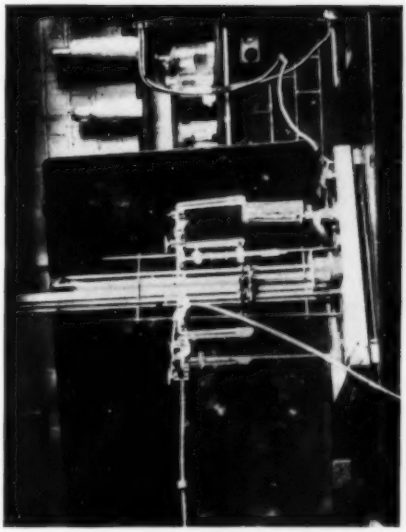


FIG. 8.

TROPSCH-DITTRICH CONDENSATION APPARATUS.

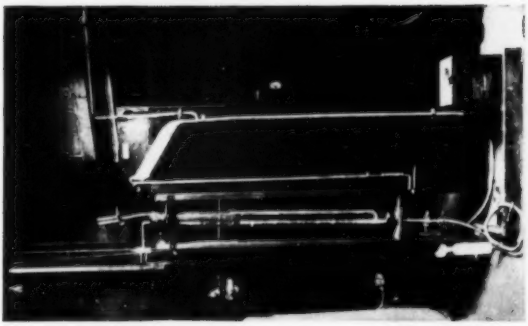


FIG. 7.

TOEPLER PUMP AND GAS BURETTE.

In view of these results, the Author is of opinion that an electrical disintegration process, having for its object the production of acetylene and a good grade carbon black from natural gas, would have a good chance of industrial success, particularly where cheap electrical energy were available.

There are a number of patents covering the production of hydrocyanic acid by the action of the electric discharge on methane-nitrogen mixtures[38], but none of these seem to be used commercially.

Conclusion.—The better utilisation of the simpler gaseous paraffin hydrocarbons is now recognised to be a problem of outstanding importance. In particular the simplest and most abundant hydrocarbon, methane, is being intensively studied with a view to its utilisation in chemical synthesis and for the production of synthetic motor spirits, etc. In the opinion of the Author, there is a fertile field of pure chemical research in the investigation of the chemical activity of methane in a highly-compressed condition. Moreover, it can be said that the chemistry of methane and its homologues is imperfectly known, especially in the range of high temperature and high pressure reactions, which are likely to provide clues to their economic utilisation. It is necessary to point out, however, that synthetic processes should be used with a certain amount of restraint, otherwise the chemical market is likely to be inundated with large supplies of certain products to the detriment of industry generally.

Part II.—" Cracking " Gas.

The term " cracking," as applied to petroleum technology, is employed to designate processes of thermally treating higher hydrocarbons in such a way that considerable conversion to more volatile hydrocarbons of lower molecular weight, suitable as motor fuels, takes place. At the same time, quantities of permanent gas are invariably produced and this gas is referred to in this paper as " cracking " gas. In the early days of the cracking process, considerable carbon formation also occurred but the development of the cracking process and the more precise control of plant operations have made it possible to avoid carbon formation to some extent.

Without entering into a detailed description of the methods now employed in the cracking of hydrocarbons, it may be briefly stated that modern commercially-operated " cracking" processes are divisible into two main classes, namely :—

1. Vapour-phase processes, in which the oil is first vaporised and the hydrocarbon vapours are subjected to heating to produce light hydrocarbons. Temperatures of the order of 600°C. and over

are employed in vapour phase processes and the use of steam and catalysts may form part of the process.

2. Liquid-phase processes, in which heat is directly applied to the oil in liquid form with some part of the liquid in contact with vapour. Pressures up to 1,000 lb./sq. in. have been employed and temperatures in the neighbourhood of 450°–480°C.

Up to the present, liquid phase processes seem to be much more prominent, but there are indications that great developments are taking place in the realm of vapour-phase cracking very largely on account of the highly anti-knock gasoline produced by such processes. Typical examples of liquid phase processes are those of Cross and Dubbs, while vapour phase cracking processes are examplified by the Rittman and Gyro installations.

Gas Production in Cracking.—While practically all cracking processes give rise to quantities of permanently gaseous products, the yield and composition of the gas so produced depend upon a number of factors such as type of plant used, operating conditions, pressure, charging stock but more particularly on the temperature at which the decomposition is effected.

In general it may be said that vapour phase cracking results in the production of much more gas than the liquid phase processes. Whereas vapour phase cracking normally gives about 1000 cu. ft. of gas per bbl. of oil the gas yield from liquid phase processes varies from 100 to 350 cu. ft. per bbl. of oil. Normal vapour phase cracking produces roughly the same yield of gas as of spirit but if the temperature of cracking is increased to 700°C., or higher, the yield of gas is greatly increased. High temperature cracking for the production of large quantities of gas rich in olefine hydrocarbons might easily be an economic proposition.

The quantities of gas available from cracking operations are very large. Egloff[39] has estimated that in 1927 the approximate quantity of gas produced by cracking processes was of the order of 200,000,000,000 cu. ft., a quantity which will be easily surpassed by the figure for 1928. Wagner[40], in a description of some recent developments in vapour phase cracking, states that in a modern Gyro plant a throughput of 4,000 bbl. of gas oil resulted in the production of nearly 5,000,000 cu. ft. of gas containing olefine gases to the extent of about 1,350,000 cu. ft. of ethylene, 800,000 cu. ft. of propylene, and 450,000 cu. ft. of the three butylenes. As the cracking process is extended to meet the demands of motor spirit users, the available supply of these gaseous substances will be further increased. Moreover, it appears probable that the cracking process will be applied to such substances as coal tar,

low temperature tar, shale oil, and other low grade hydrocarbon materials.

Composition of Cracking Gas.—As previously stated, the composition of the gas varies with the conditions of cracking and the nature of the charging stock but a few generalisations may be made. Liquid phase cracking at temperatures of 450°–480°C gives rise to a gas containing large proportions of gaseous paraffin hydrocarbons, comparatively small amounts of olefine gases and only a little hydrogen; while propylene seems to be the main olefinic constituent, ethylene occurring to a smaller extent. Practically no diolefines are present in liquid phase cracking gas. On the other hand, vapour phase cracking results in a gas relatively rich in olefines (up to 60 per cent. of total), ethylene here forming the preponderating olefinic constituent. Moreover, diolefines such as butadiene are present to the extent of 2 per cent., as well as traces of acetylene and quantities of hydrogen (up to 10 per cent.).

Typical analyses of gases from liquid phase cracking plants are given in the table below[39].

Constituent.		1	2	3	4
Hydrogen, per cent.	.. ..	1·9	5·6	3·0	1·7
Ethylene „	.. ..	1·9	4·7	2·7	6·3
Propylene „	.. ..	0·8	6·1	7·6	12·0
Butylenes „	.. ..	7·4	2·0	6·5	7·1
Paraffins „	.. ..	88·0	81·6	80·2	72·9

The cracking gas used by Ellis[41] for the production of isopropyl alcohol was obtained from Burton stills and contained about 5 per cent. of available olefines, about 2—3 per cent. being ethylene.

A typical analysis of a gas from a vapour-phase cracking process (Gyro) is given below[40].

Constituent.	Per cent.
CO_2+H_2S	0·25
CO	0·15
H_2	7·00
Ethylene	27·00
Propylene	16·00
Butylenes	9·00
Butadiene	1·00
Paraffins	39·60

Dunstan[39] quotes the following figures for the unsaturated hydrocarbon content (*i.e.*, 55 per cent. of total gas) in a vapour phase cracking process :—

Constituent.	Per cent.
Ethylene	54·0
Propylene	28·0
Butylenes	9·0
Amylenes	1·7
Higher olefines	6·1
Butadiene	1·2

Thus, cracking gas is invariably a complex mixture, containing most of the following constituents :—methane, ethane, propane, butanes, and high paraffins ; ethylene, propylene, butylenes, and higher olefines; hydrogen, butadiene, and probably a little acetylene as well as carbon dioxide and sulphuretted hydrogen.

The Olefines.—The olefine gases are at once the most characteristic, and at the same time, on account of their chemical activity, the most important, constituents of cracking gas. These olefines are capable of combination with numerous reagents yielding many products of established commercial importance and utility. A few of the physical properties of the gaseous olefines are tabulated below.

Name.	Formula.	b.pt. °C.	m.pt. °C.	Crit. temp. °C.	Crit. pressure. Atmos.	Calorific value. Cals. per gm. mol.
Ethylene	$CH_2=CH_2$	—103·9°	—169°	9·7°	50·9	345,800
Propylene	$CH_3{\cdot}CH=CH_2$	—47·0°	—185·2°	92·3°	45·0	492,700
Butene–1	$CH_3{\cdot}CH_2{\cdot}CH=CH_2$	—5°				650,600 (average)
Butene–2	$CH_3CH=CH{\cdot}CH_3$	+1·4° (cis) +2·5° (trans)				
Isobutylene	$CH_3{>}C{=}CH_2$ (CH_3)	—6°				

Butadiene, a substance having the constitution,

$$CH_2=CH—CH=CH_2$$

is a gas at ordinary temperature ; liquefying at –5° C.

Analysis of Cracking Gas.—Many of the methods of analysis of natural gas, outlined in Part I. of this paper, are also applicable to the analysis of cracking gas, which may be regarded as a natural gas diluted with olefine gases and hydrogen. When, for example, a cracking gas is analysed in the condensation apparatus of Tropsch and Dittrich[4], there are obtained various fractions, each of which contains two paraffin hydrocarbons admixed with the two analogous olefine hydrocarbons. For the analysis of such a mixture,

Tropsch and Dittrich recommend that the olefines be absorbed by means of 87 per cent. sulphuric acid, and ethylene by means of the same acid activated with nickel and silver sulphates. The average number of carbon atoms associated with the olefine gases in any particular sample is then determined by oxidation of the sulphuric acid solution, thus obtained, by means of excess potassium iodate, followed by back titration of the iodate by means of thiosulphate. The residual paraffin gas mixture is then analysed by combustion or explosion methods.

The distillation methods developed by Podbielniak[9] and also by Davis[10] are applicable to the analysis of cracking gas as well as of natural gas and will undoubtedly be generally utilised for plant control purposes.

In connection with the evaluation of the unsaturated hydrocarbon constituents of cracking gas, brief reference must be made to the methods developed by Manning, King, and Sinnatt[42], which, though used in the examination of low temperature carbonisation (coal) gases, would be equally applicable to the case of cracking gas. Their method consists in converting all the olefines into their bromine addition compounds, followed by fractionation of the resulting liquid mixture under reduced pressure (20 mm.), the following fractions being collected.

(*a*) Up to 80°C/20 mm. This fraction contains all the ethylene and propylene dibromides, and most of the butylene dibromides.

(*b*) 80°–130°C/20 mm. This contains remaining butylene dibromides together with bromine derivatives of higher olefines.

(*c*) Residue, which would consist, in the case of cracking gas, of butadiene tetrabromide almost entirely.

The procedure recommended involves the liberation of the mixed olefines from known weights of fractions (*a*) and (*b*) by means of the zinc-copper couple, followed by an examination of the gases produced, by the following processes :—

1. The total percentage of olefines is determined by absorption in fuming sulphuric acid or bromine water.

2. A second portion of the gas is burned completely over copper oxide at 700°C and the carbon dioxide produced is determined.

3. Another portion of the gas is treated successively with 2 cc. of 87 per cent. H_2SO_4 for 5 minutes at each treatment. The olefines higher than ethylene are absorbed completely in 20 minutes at ordinary temperature. After this period the absorption per 5 mins. becomes small and constant and is due to ethylene only. A determination of this rate enables a correction to be made for the ethylene absorbed during the first 20 mins.

From the above data it is possible to calculate the actual percentage of the individual olefines in a mixture of ethylene, propylene and butylenes.

This method of procedure has been recently examined in this Department in conjunction with the Tropsch-Dittrich method by the Author and can be recommended as a reliable method. The process of preferentially absorbing olefines higher than ethylene by 87 per cent. sulphuric acid has also been checked.

The chart, given below (Fig. 11), which lists the known gaseous hydrocarbons according to their boiling points on the Centigrade scale, is helpful in showing clearly the difficulties associated with the fundamental analysis of such hydrocarbon mixtures.

Fortunately their number is limited to a little over twenty individuals, scattered over a temperature range of 170°C and only a rare mixture, if any, would contain them all.

The Utilisation of Cracking Gas.—Cracking gas has a very high calorific value, which may be as much as 1700 B.Th.U. per cu. ft., and rarely falls below 1200 B.Th.U. per cu. ft., and hence is to be regarded as a very high-grade gaseous fuel. Although the major part of cracking gas is still being used merely as a fuel, the present trend of development is for the olefine content of this gas to be utilised for chemical synthesis. More and more is it being realised that the production of these vast supplies of olefine gases possessing great chemical reactivity and unusual power of condensation is a fact of prime importance to chemical industry. In other words, the olefines in cracking gas must be used, wherever possible, as sources of alcohols, glycols and the numerous other compounds derived from them.

1. *Fuel.*—As in the case of natural gas, the most economical method of using cracking gas as a fuel is as an enricher in lower grade gases such as water-gas, producer gas, etc. Plants not immediately in the vicinity of water gas plants or producer gas plants could very readily liquefy the propylene and butylene fraction and ship it in tank cars for gas enrichment purposes, exactly as is done in the case of propane and the butanes (*e.g.*, " Skelgas "). The residual gas after removal of these olefines could be used as a plant fuel.

On account of their particular properties some of the individual olefines of " cracking " gas are assuming a position of some importance in various directions. For example, ethylene is now commercially available compressed in steel cylinders for welding and cutting purposes. Ethylene is also becoming prominent as an anaesthetic and also for the artificial ripening of fruit and vegetables.

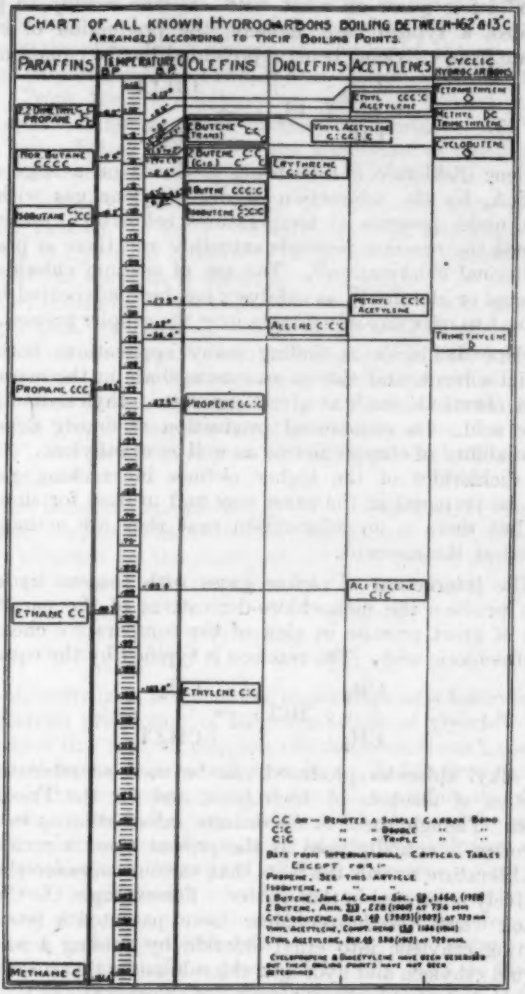


FIG. 11.

(AFTER DAVIS.)

Reproduced from "Ind. Eng. Chem.," Analytical Edition, 1929, 1, 62.

2. *Production of Halogen Derivatives of Olefines in Cracking Gas.*—(*a*) The olefine gases all react with chlorine readily to produce dichlorides, a typical case, namely, the production of ethylene dichloride from ethylene, being represented by the equation :—

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + Cl_2 \longrightarrow \begin{matrix} CH_2Cl \\ | \\ CH_2Cl \end{matrix}$$

Ethylene dichloride is now being produced on a large scale in the U.S.A. by the interaction of dry ethylene gas with liquid chlorine under pressure at temperatures below 0°C., under which conditions the reaction proceeds smoothly and there is practically no additional chlorination[43]. The use of calcium chloride[44], and of charcoal or alumina[45], as catalysts has been advocated but does not appear to offer any advantages over the simpler process.

Ethylene dichloride is finding many applications both as an industrial solvent, and also as an intermediate in the manufacture of other chemicals, such as glycol diacetate, ethylenediamine, and succinic acid. Its economical production obviously depends on the availability of cheap chlorine as well as of ethylene.

The dichlorides of the higher olefines in cracking gas could readily be prepared in the same way and utilised for similar purposes, but there is no information that they are actually being produced at the moment.

(*b*) The interaction of olefine gases with gaseous hydrochloric acid to produce the monochloro-derivatives of the paraffins is a process of great promise in view of the comparative cheapness of the hydrochloric acid. The reaction is typified by the equation :

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + HCl \longrightarrow \begin{matrix} CH_3 \\ | \\ CH_2Cl \end{matrix}$$

The alkyl chlorides produced can be used as solvents, in the production of alcohols by hydrolysis, and for the Friedel-Crafts reaction. Though there is no definite information as to whether this process is actually used at the present time, a review of the patent literature reveals the facts that various commercial concerns are actively interested in this matter. For example, the Chemische Fabriken vorm. Weiler-ter Meer have patented a process[46] for converting ethylene into ethyl chloride by passing a mixture of dry liquid ethylene and hydrogen chloride under 60 atmos. pressure over a catalyst of anhydrous aluminium chloride at –15°C. Another patent[47] of the same firm proposes the use of a catalyst composed of the double compound of aluminium chloride and ethylene, dispersed on a porous supporting material, temperatures of about

90°C. and ordinary, or high, pressures being employed. The yield of ethyl chloride is said to be 66 per cent. of the ethylene. The direct combination of equal parts of dry ethylene and dry hydrogen chloride in the presence of anhydrous aluminium chloride at 15°C has been patented by the Carbide and Carbon Chemical Corporation[48]. From the very interesting work of Wibaut and his collaborators[49] it appears that bismuth trichloride at 150°–200°C forms a very efficient catalyst for the interaction of equal parts of ethylene and hydrogen chloride to form ethyl chloride.

Finally, mention must be made in this connection of some interesting patents[50] of the T. Goldschmidt A. G. which specify the interaction of hydrogen chloride with olefine gas mixtures in such a way that the ethylene is virtually unattacked. For example, a gas mixture containing 6 per cent. butylenes, 17 per cent. propylene, and 27 per cent. ethylene, as well as 50 per cent. methane (which corresponds with a vapour-phase cracking gas) is mixed with the requisite amount of dry hydrogen chloride and passed at 15° over a contact mass consisting essentially of anhydrous ferric chloride. Butyl and n-propyl chlorides are obtained by cooling the reaction gas to –60°, and the residual gas contains 30 per cent. ethylene and 70 per cent. methane.

(*c*) Some halogen derivatives (of the olefine gases) which are becoming of very great industrial importance are the chlorohydrins which are obtained by the combination of an olefine with hypochlorous acid, a process exemplified by the case of ethylene :

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + H\,O\,Cl \longrightarrow \begin{matrix} CH_2\,OH \\ | \\ CH_2\,Cl \end{matrix}$$

These chlorohydrins are of great importance as intermediates in the commercial production of large quantities of glycols[27]. More particularly is this true of ethylene chlorohydrin though there are indications that the process will soon be applied to propylene and butylenes. The processes employed for the manufacture of these chlorohydrins in the U.S.A. are mostly modifications of the reaction between the olefine gas and a solution of free hypochlorous acid in sodium hypochlorite. As typical of these processes we may take a patent of Young[51], which specifies the passage of a mixture of ethylene and propylene through a solution containing free hypochlorous acid (not more than 0·09 per cent.) and sodium hypochlorite (5–7 per cent.). In a patent of E. I du Pont de Nemours and Co.[51], a solution of 5 per cent. sodium hypochlorite is recommended, the slight concentration of free hypochlorous acid being maintained by passage into this solution of regulated quantities of carbon dioxide.

Anhydrous ethylene chlorohydrin is a remarkable solvent, and patents for its use as a solvent for cellulose acetate have been taken out. It is a very reactive substance and has been used extensively in the past for the manufacture of indigo, mustard gas (yperite) and novocain, but is now used largely for the manufacture of ethylene oxide and ethylene glycol by processes which will be discussed later.[53]

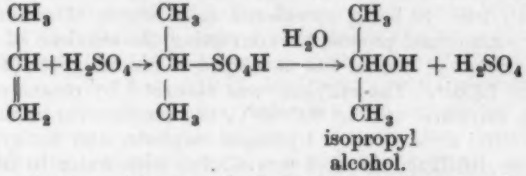
Production of Alcohols from Olefines.—At the present time the most important industrial method for utilising the olefine content of cracking gas is by conversion into the corresponding alcohol by addition of the elements of water. The most important companies actually engaged on this work are the Petroleum Chemical Corporation, the Standard Oil Company of New Jersey, and the Empire Refineries Company. The chief alcohols produced at the moment are isopropyl alcohol, secondary and tertiary butyl alcohols, and secondary amyl alcohol of which isopropyl alcohol is by far the most important from the viewpoint of quantity available. The higher alcohols, including secondary hexyl, heptyl, and octyl alcohols which are the more valuable from a commercial point of view, but available to a much smaller extent, will doubtless soon be produced in quantity.

At the present time it does not appear that ethyl alcohol is being produced from ethylene to any appreciable extent, but, in view of the development of vapour phase cracking with the resulting production of very large quantities of ethylene, it is extremely likely that this process will be used commercially. Accordingly, the methods which can be used for converting ethylene into ethyl alcohol will be discussed under a separate head.

The alcohols are probably some of the most important organic compounds of commerce. Isopropyl alcohol is extensively used at the present time as a solvent (because of its anhydrous nature); as a dehydrating agent for such materials as sugars, starches, proteins, gelatin, etc., as a substitute for rectified spirit in perfumes and nitro-cellulose lacquers and as a precipitant for proteins, as well as in the manufacture of synthetic chemicals. Probably the most important of the present and potential uses of the other alcohols are as solvents and raw materials for chemical synthesis. The rapid growth of the pyroxylin lacquer and rayon industries has greatly increased the demand for volatile solvents and has encouraged the manufacture of many new derivatives. Among the latter, the esters of the higher alcohols are bound to assume an important place.

Theoretically the conversion of an olefine into an alcohol takes place by an addition of the elements of water to the olefine molecule,

a reaction which is difficult to effect, however, directly. A study of the literature indicates that the process used almost exclusively for the manufacture of isopropyl, and higher, alcohols, consists in dissolving the olefine gas in sulphuric acid of suitable concentration, followed by dilution with water and subsequent distillation. The reactions involved are exemplified by the case of propylene, as follows :—



isopropyl alcohol.

The first production of isopropyl alcohol was undertaken by the Standard Oil Company of New Jersey in 1919 by the Ellis process[54]. The gas used was derived from Burton cracking stills, and, after being purified, was conducted through 87 per cent. sulphuric acid in batch absorbers or towers, the temperature being maintained below 20°C. The product was diluted with several volumes of water and distilled, a crude 20 per cent. aqueous isopropyl alcohol being obtained, which was concentrated by distillation. The dilute sulphuric acid was concentrated and used again.

The fullest details of the process as applied to mixtures of propylene, butylenes, and other olefines have been given by H. S. Davis and the Petroleum Chemical Corporation in their various patents[55], which should be consulted for an exhaustive explanation of the process. The process is briefly as follows :—

The gases are first desulphurised and separated into fractions by washing with cooled gas oil which dissolves the butylenes and higher olefines. The gas escaping from the scrubbers, containing propylene and ethylene, is converted into isopropyl alcohol by solution in 93–100 per cent. sulphuric acid, the temperature of the acid being kept below 30°C to prevent polymerisation. The gas oil from the scrubbers passes into a still and yields up its dissolved butylenes and amylenes. By suitably adjusting the temperature and pressure, the amylenes are condensed and the butylenes pass on in gaseous form for treatment with acid. The butylene and amylene fractions are then treated with 60 per cent. sulphuric acid to convert the iso-hydrocarbons into tertiary alcohols, while a further treatment of the unabsorbed butylenes and amylenes with 75–83 per cent. acid suffices to convert them into secondary alcohols. Thus, for example, both butene—1 and butene—2 give rise to the same alcohol, namely butanol—2, or secondary butyl alcohol.

Production of Ethyl Alcohol.—As previously stated, although little or no ethyl alcohol is at present being manufactured from the ethylene of cracking gas, yet the very large quantities of ethylene which will result from a development of vapour-phase cracking, will undoubtedly be utilised, in part at least, for the manufacture of this substance. Especially is this true in view of the fact that, on the Continent, coke oven gas, containing only small percentages of ethylene, is being considered as a source of alcohol.

A commercial process for converting the ethylene of coke oven gas into ethyl alcohol was developed at Skinningrove (England) in about 1920[56]. The ethylene was absorbed by means of 95·4 per cent. sulphuric acid at 60°–80°C, the product containing, besides free ethyl alcohol, ethyl hydrogen sulphate, and diethyl sulphate. Before distilling, the acid was diluted with water to 64 per cent. strength. The yield was about 1·6 gallons of 95 per cent. alcohol per ton of coal carbonised.

Ethylene requires much stronger acid and higher temperatures than do its higher homologues, and Ellis has commented unfavourably on this, since polymerisation and carbonisation are very liable to occur. It has been found, however, that catalysts can greatly reduce the temperature, and acid concentration necessary for good absorption, and thus will be of great value. For example, Damiens[57] showed that 5 per cent. cuprous oxide had a pronounced catalytic effect, while the use of silver sulphate as a catalyst has been proposed by Gluud and his collaborators and others[58]. Gerr and Popov[59] have worked out a process whereby ethylene-containing gases, freed from higher homologues of ethylene, are passed through 94 per cent. sulphuric acid containing 1 per cent. of silver sulphate as catalyst, at 40°C. On diluting and distilling, a good yield of alcohol is obtained.

All the processes previously described for coverting olefines into alcohols involve the intervention of sulphuric acid. There are quite a number of patented processes, however, which refer to a direct combination of ethylene and water according to the scheme:

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + H_2O \rightarrow \begin{matrix} CH_3 \\ | \\ CH_2—OH \end{matrix}$$

and these appear to be extremely promising, in the opinion of the Author, since the troublesome and expensive acid treatment is thereby entirely avoided. No apology is needed for quoting a number of these patents at some length since they appear to indicate an excellent method for utilising ethylene. Thus, a patent of Johannsen and Gross[60] proposes to heat olefines, such as ethylene in the presence of water and an acid to a temperature at

least as high as the boiling point of water, under a pressure of about 20 atmos. to produce alcohols. In some patents of the Röchlingsche Eisen-und Stahlwerke A.G.[61], it is proposed to heat ethylene with a solution of 4·3 per cent. hydrochloric acid in water at about 220° under 75–200 atmos. pressure. The yield of alcohol is 63 per cent. on the ethylene used, a result sufficiently good to justify further research. The reaction is said to be assisted by suitable contact materials. Finally, a recent patent of Slade and Imperial Chemical Industries Ltd.[62] claims the conversion of ethylene into ethyl alcohol by reaction with steam (5–10 vols. of ethylene per 1 vol. of steam) at 400°–500°C. and pressures of 25–200 atmos., using high space velocities and a catalyst such as thoria or phosphoric acid on charcoal. All these processes probably refer to coke-oven gas as a source of ethylene; in this respect coke oven gas is markedly inferior to vapour phase cracking gas.

Conversion of Olefines into Glycols.—The glycols, or dihydric alcohols and more particularly ethylene glycol,

$$\begin{array}{l} CH_2—OH \\ | \\ CH_2—OH \end{array}$$

possess properties which render them of immense commercial value. Ethylene glycol is used extensively as an " antifreeze " agent in motor car radiators. It is miscible in all proportions with water, alcohol, and glycerol, has been used as a lubricant in the spinning of textiles, and is finding many applications in the production of industrially valuable derivatives, such as glycol dinitrate (useful as a low-freezing explosive, very resistant to shock), glycol monoethyl ether, and glycol monobutyl ether, the two latter being valuable solvents for nitrocellulose, resins, and organic liquids[63].

Ethylene glycol and its homologues are made commercially from the corresponding chlorohydrins by hydrolysis by means of aqueous sodium bicarbonate at 105° under pressure[64]. The use of stronger alkalies results in the production of olefine oxides from chlorohydrins. These reactions may be expressed as follows :—

$$\begin{array}{l} CH_2 \\ | \\ \quad O \\ | \\ CH_2 \end{array} \xleftarrow{\text{strong alkalies}} \begin{array}{l} CH_2OH \\ | \\ CH_2Cl \end{array} \xrightarrow{\text{sodium bicarbonate}} \begin{array}{l} CH_2\ OH \\ | \\ CH_2OH \end{array}$$

The olefine oxides may be converted into glycols by treatment with sulphuric acid[65]. Another process for preparing these glycols (which is not used industrially, however) consists in the interaction

of an olefine dichloride with an aqueous alcoholic solution of sodium carbonate and sodium acetate at 150°C under a pressure of 12.5 atms.[66].

Conversion of Olefines into Higher Hydrocarbons.—Of recent years the possibility of converting the olefine gases into liquid hydrocarbons suitable as motor fuels, lubricants, etc., by a process of controlled polymerisation, has been very much discussed and, from private information, would seem to be the object of much intensive work. For instance, Wagner[40] writes: " A third use for (cracking) gas which bids fair to consume the major portion of its unsaturated hydrocarbon content is in the synthesis of motor fuel. Some preliminary experiments along this line indicate that a very highly anti-knock product, especially suited for aviation motor fuel can be made from it in large quantities at low cost." It is obvious that, providing the polymerisation of olefine gases is sufficiently controllable and flexible to give rise to any desired type of product, we are here face to face with an entirely new development, which is bound to have the profoundest influence on the industry.

The processes actually being tested for this polymerisation are, of course, still veiled in secrecy, but it is not difficult from a survey of the literature to gain an insight into the recent trend of research. The polymerisation of olefines to liquid products might be brought about by the following agencies :—

1. By heat and pressure.
2. By catalysts preferably with pressure and possibly heat.
3. By silent discharge.
4. By ultra-violet light and similar sources of energy.

Of these, the first two need only be considered from a commercial point of view, the latter two being of scientific interest only. Considering the first type of reactions, Ipatiev[64] found that under 70 atmos. pressure ethylene commenced to polymerise at 325°C; the process of polymerisation was moderately rapid at 350° and very rapid at 380°–400°C. Forty to fifty grams of liquid products, boiling between 24°–over 280°C, were obtained from 30 litres of ethylene but no polymerisation occurred without pressure.

A patent of the I.G. Farbenindustrie A.G.[65] specifies the passage of ethylene in a continuous stream at 400° and under 40 atmos. pressure over active carbon. The condensed products are then conducted under a pressure of 5 atmos. over a molybdate catalyst at 600°, whereby benzene and its homologues are produced. A more recent patent of the same firm[66] specifies the passage of olefines or gases containing them, over a heated catalyst under

pressure; the catalyst consists of a metal which has been coated by heat treatment with tin, zinc, aluminium and chromium. Under these conditions liquid hydrocarbons are produced.

The importance of various catalysts in the polymerisation of the typical olefine, ethylene, to liquid products, is well known. Activated sulphuric acid, aluminium chloride, antimony chlorides, and many other substances all induce polymerisation to a marked degree. Thus, for example, Otto[67] found that boron fluoride polymerised ethylene extensively under pressure at ordinary temperature while its homologues were even more easily converted into higher hydrocarbons. The products were said to be comparable with the best American lubricating oils.

The various patents of Allenet[68] are of very great interest since they advocate the passage of ethylene or other olefine gases into a heavy oil containing aluminium chloride. Extensive polymerisation occurs at ordinary temperatures. In this connection Krauch[29] has communicated some important results obtained by the I.G. Farbenindustrie. Using this process, namely, a suspension of aluminium chloride in petroleum ether into which gaseous olefines were passed, it was found that polymerisation to lubricant hydrocarbons of high molecular weight took place. When olefines were passed into suspensions of aluminium chloride in middle oils, not only did polymerisation processes occur, but also condensations between the middle oil hydrocarbons and the olefines introduced. The result is that, out of a thin middle oil, highly viscous lubricating oils are obtained which are essentially similar in properties to natural oils of a similar character. It seems likely, therefore, that the production of synthetic lubricants by the aid of aluminium chloride is not far distant.

Processes similar to that of Allenet have been patented by Ramage[69] and the production of light hydrocarbons of the butadiene series by thermal treatment of ethylene has been patented by Weinmann[70] and others, the obvious object here being the conversion of these butadiene derivatives into synthetic rubber.

The action of the silent electric discharge on ethylene and its homologues has recently been examined[71] and found to give rise to a wide variety of liquid products. The reaction proceeds more smoothly as the series of ethylene homologues is ascended, *i.e.*, as molecular weight increases. A German firm is at the present time using the silent discharge for the commercial production of lubricants from mineral and fatty oils[71], but it is doubtful whether the process would ever be economic in the case of cracking gas. In the same way, the polymerisation of ethylene and its homologues by means of ultra-violet light[73] is never likely to be of any commercial importance.

Conclusion.—While realising that it is quite impossible to deal exhaustively with the synthetic possibilities of cracking gas in a paper of this scope, it is hoped that an indication has been given as to the modern trend of development and also to the future possibilities. Briefly, it may be stated that, of the processes which can be employed for the industrial utilisation of the olefine content of cracking gas, the most promising can be tabulated in their order of importance, as follows:—

1. Polymerisation of olefine gas to liquid hydrocarbons, capable of being used as motor fuels and lubricants.

2. Conversion of olefines into alcohols, glycols, chlorohydrins and their derivatives.

Besides the processes previously mentioned in this paper, there are a few other methods of utilising olefines which have been propounded from time to time, among which may be mentioned the following:—

1. Manufacture of diethyl sulphate from ethylene[74].

2. Oxidation of olefines to aldehydes, etc., more particularly the oxidation of ethylene to formaldehyde[75].

3. Utilisation of olefine gases for the manufacture of cyanides by interaction with nitrous oxide at high temperature[76].

Finally, it has been suggested to use the diolefines, present in cracking gas to the extent of 2 per cent., as raw materials for the manufacture of synthetic rubber. A review[22] of the economic aspects of the situation, however, indicates that the possibility of using such a process is very remote.

Department of Oil Engineering and Refining,
University of Birmingham.

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

STUDENTS' SECTION, LONDON BRANCH.

A MEETING of the London Branch of the Students' Section of the Institution of Petroleum Technologists was held at Aldine House, Bedford Street, London, W.C. 2, on May 28, 1929. A precis of the paper which was read follows.

Low-Temperature Carbonisation.

By G. H. WILLOCK (Member).

Coal should not be considered as a black mass of carbon and hydrogen, but rather as a mixture of complexes, each of which behaves in a definite way when subjected to hydrogenation, distillation or oxidation. The subject of the conversion of coal into artificial petroleum or liquid fuels is one of great importance.

Four general types of retort are in use for the low-temperature carbonisation of coal, the present paper dealing particularly with that known as the "Dvorkovitz." This retort is of the continuous vertical type and the temperature never exceeds 500° C. Preheated inert gas is recirculated to sweep the volatile products out of the heated zone as soon as they are evolved, and to carry heat rapidly to the centre of the charge. External heat is also applied to prevent the retorts cooling down and to maintain an even temperature. The volatile products are passed through air coolers, water condensers and scrubbers.

The author also dealt with the importance of preheating certain coals before retorting, the installation of dust traps and the rate of retorting.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TRINIDAD BRANCH.

THE TWELFTH ORDINARY MEETING of the Trinidad Branch of the Institution of Petroleum Technologists was held at Comdr. H. V. Lavington's Bungalow, Palmiste, Trinidad, on April 24th, 1929. The chair was taken by Mr. A. F. Dabell, and the following is a precis of the paper read :—

The Reduction of Accidents in the Trinidad Oilfields by Co-operative Methods.

By C. A. P. SOUTHWELL, F.G.S. (Member).

It may be said that 50 per cent. of the accidents in the oil industry in Trinidad occur in drilling and production operations, the remaining 50 per cent. being in connection with storage, transport, refineries, etc. The " Safety First " slogan is not applicable to mining in any form, and all accident reduction activities can be divided into two classes : (a) education of employee and (b) safety of equipment.

Statistics of the cause and effect of all accidents should be collected and studied to ascertain how these accidents can be reduced, and special forms for these statistics are suggested. The personal factor is responsible for 80 to 90 per cent. of oilfield accidents, and the education of employees is an important factor in accident reduction. Attention is drawn to the Safety Practice Pamphlets of the Petroleum Section of the United States National Safety Council.

The author's suggestion for a safety campaign comprises : (1) The setting up of a Safety Committee, (2) each company to appoint a Safety Officer and to record accident statistics on a comparative basis, (3) the education of employees by lectures, posters, etc., (4) the standardisation of safety equipment and practice, and (5) the provision of special fire-fighting devices.

A discussion followed and was taken part in by Messrs. A. P. Catherall, A. F. Dabell, J. S. Parker, J. A. Goodwin, H. C. B. Hickling, A. J. Ruthven-Murray, H. W. Reid, W. R. Hamline, H. D. Fletcher and E. L. Ensign.

SECOND INTERNATIONAL DRILLING CONGRESS.

Paris, September 15 to 23, 1929.

In connection with the Second International Drilling Congress, held in Paris, from September 15 to 23, 1929, a British Committee was formed and was constituted as follows :—

Dr. A. E. Dunstan, D.Sc., F.I.C., F.C.S., M.Inst.P.T. (Chairman).
Ashley Carter, A.M.I.Mech.E., M.Inst.P.T.
Thomas Crook, A.R.C.S., F.G.S.
C. Dalley, M.I.E.E., M.Inst.P.T.
Prof. C. H. Desch, F.R.S.
T. Dewhurst, A.R.C.S., F.G.S., M.Inst.P.T.
F. J. Dixon, M.Inst.C.E., M.I.Mech.E.
H. P. W. Giffard.
Dr. J. A. L. Henderson, Ph.D., F.G.S., M.Inst.M.M., M.Inst.P.T.
C. Le Maistre, C.B.E.
H. M. Morgans, M.I.Min.E.
Sir Richard A. S. Redmayne, K.C.B., M.Inst.C.E.
William Sutton, M.I.Min.E., M.Inst.P.T.
Comdr. R. E. Stokes-Rees, R.N. (Secretary).

The seven papers mentioned below were arranged and submitted by the British Committee, and are reproduced in full in the following pages :—

Data Relating to Boring for Oil in Great Britain. By J. Allen Howe, O.B.E., of the Geological Survey of Great Britain.

Geophysical Work in Great Britain. By W. F. P. McLintock, D.Sc., and James Phemister, M.A., of the Geological Survey of Great Britain.

The Mintrop Seismic Method. By Ernest H. Neville, of the Geophysica Company, Ltd.

Drilling on the Gold Coast, West Africa. By O. A. L. Whitelaw, F.G.S., F.R.G.S., M.Inst.M.M., of the Gold Coast Geological Survey.

Wire Lines. By B. J. Ellis, M.Inst.P.T.

Electrification of Oilfields. By W. S. Toplis, M.I.E.E., M.I.Min.E.

The Use of Steel in the Oil Industry with a Special Reference to Heat Resisting Steels. By Sir Robert Hadfield, Bt., F.R.S., M.Inst.C.E., and S. A. Main, B.Sc.(Hons.), F.Inst.P., of The Hadfield Research Laboratories, Sheffield.

Mr. Ashley Carter attended as the Delegate of The Institution of Petroleum Technologists, and about 250 to 300 persons were present at the various sessions.

The opening session on September 15 was of a formal character, the various delegates being called upon to speak. Mr. Ashley Carter, in expressing the good wishes of the President and Members of the Institution and thanks to those responsible for the organisation of the Congress, also expressed the regret of the President of the Institution at being unable to attend.

The Congress proper opened on September 16 and continued in two daily sessions until September 18, upwards of fifty papers being presented, the majority of which dealt with drilling and its various problems. In connection with the Congress several social gatherings were held, including a banquet, receptions and lunch, and visits were paid to mining and oil centres.

It is understood that the papers and general report of the Congress will be published in a similar form to that of the First International Drilling Congress, held in Rumania four years ago, and that arrangements have been made for the next Congress to be held in Berlin in 1931. The Secretariat will in future be located in Brussels.

Data Relating to Boring in Great Britain.

By J. Allen Howe, O.B.E.

(Geological Survey of Great Britain).

With the exception of a very limited amount of boring for oil between 1918 and 1922, practically all drilling in this country has been in search of coal or water.

Prior to 1918 there existed no Government control over borings for any purpose, but the Geological Survey, as one of its regular duties, collected all the information it could from the mining industry and from water authorities and water-boring engineers. A great deal of information was gathered in this way by personal contact with mine managers and owners or from water engineers in return for advice upon the geological aspects of their problems.

Data so obtained were of the greatest value to the industries concerned and to the Geological Survey, and much of the information was made public in the form of memoirs, sheets of sections and the like ; it was also utilised in the preparation of the detailed maps of the coalfields on the scale of six inches to one mile. But since it was all contributed by the voluntary action of the officials and engineers it was only natural that there were gaps in the records existing of new borings. The occasions when information was refused to the Geological Survey were fortunately rare.

The Petroleum (Production) Act, 1918.

"An Act to make provision with respect to the searching and boring for and getting petroleum, and for purposes connected therewith," was passed in 1918 as a result of the special activity about that time in prospecting for oil in Great Britain. The following provisions should be noted :—

No person other than a person acting on behalf of His Majesty, or holding a licence under this Act for the purpose, shall search or bore for or get petroleum within the United Kingdom, and if any person gets petroleum in the United Kingdom in contravention of this provision he shall forfeit to His Majesty a sum equal to three times the value of any petroleum gotten by him.

For the purpose of ascertaining on behalf of the Minister of Munitions the position of the workings, actual and prospective, of any mines or abandoned mines through or near which it is proposed to sink any shaft or borehole for the purpose of searching for or getting petroleum, any officer appointed by the Director of the Geological Survey shall have the same rights as to the production and examination of plans and sections kept in pursuance of sections

20 or 21 of the Coal Mines Act, 1911, or sections 14 or 19 of the Metalliferous Mines Regulation Act, 1872, as are by those Acts conferred on inspectors, and those sections shall apply accordingly.

Any person entitled to sink a shaft or borehole for the purpose of searching for or getting petroleum shall before commencing to sink the same give notice in writing of his intention to the Director of the Geological Survey and shall keep a journal of any such shaft or borehole, and shall retain for a period of not less than six months such specimens of the strata passed through as may have been obtained in the course of the sinking thereof, either as cores or fragments, and shall allow the Director of the Geological Survey or any officer appointed by him to have free access to any such shaft or borehole whilst in process of being sunk, and to inspect all specimens so obtained and kept and the journals of such shafts and boreholes, and if any person fails to comply with any obligation imposed on him by this provision he shall on summary conviction be liable to a fine not exceeding £50.

Mining Industry Act, 1926.

This is "an Act to make provision for facilitating the working of minerals and the better organisation of the coal mining industry, and with respect to the welfare of persons employed therein and for other purposes connected with that industry."

Clause 23 of this Act gives facilities to the Department of Scientific and Industrial Research in respect of boreholes and shafts sunk in the search for minerals.

The duty of inspecting, collecting from and recording the facts obtained from boreholes and shafts put down for minerals, including coal, is delegated by the Department to the Geological Survey, and when the Act came into force the following statement was circulated to all mining companies and boring firms in this country:—

DEPARTMENT OT SCIENTIFIC AND INDUSTRIAL RESEARCH.

Notification of New Boreholes and Shafts.

The attention of coal masters, mining engineers, shaft sinkers, mineral borers and all persons concerned is directed to the provisions of the Mining Industry Act (1926) embodied in the following clauses:—

23.—(1) Before any person sinks, for the purpose of searching for or getting any minerals, a shaft or borehole intended to reach a depth of more than one hundred feet below the surface he shall give to the committee of the Privy Council for Scientific and Industrial Research (hereinafter referred to as "the committee") notice in writing of his intention to do so, and any person who for such a purpose sinks any such shaft or borehole shall keep a journal thereof, and shall retain for a period of not less than six months such specimens of the strata passed through as may have been obtained in the course of the sinking thereof, either as cores or fragments, and shall allow the committee, or any officer appointed by them, to have free access at all reasonable times to any such shafts or boreholes, to inspect all specimens so obtained and kept, and to take representative specimens of any such cores.

(2) If the person sinking any such shaft or borehole as aforesaid gives notice in writing to the committee requiring them to treat as confidential any copies of journals or specimens so taken by the committee or by any officer appointed by them, the Committee shall not allow those copies or specimens to be published or shown to any person not being an officer of the Department of Scientific and Industrial Research, except with the consent of the person sinking such shaft or borehole:

Provided that, if at any time the committee give notice to any person from whom such consent is required that, in their opinion, his consent is unreasonably withheld, then that person may, within three months after such notice is given, appeal to the Railway and Canal Commission, but if at the expiration of that period no such appeal has been made, or if after hearing the appeal the Commission do not make an order restraining them from doing so, the committee may proceed as if such consent had been given.

(3) The owner, agent or manager of every mine shall allow the committee or any officer appointed by them to have free access at all reasonable times to all underground workings, and shall supply to the committee or to any such officer as aforesaid such information and such specimens of seams or strata sunk through or opened out at the mine as may be reasonably required by the committee.

(4) If any person sinking any shaft or borehole, or the owner, agent or manager of any mine fails to comply with any obligation imposed on him by the foregoing provisions of this section, he shall, in respect of each offence, be liable on summary conviction to a fine not exceeding £50.

(5) Any officer appointed by the committee shall have the same rights as to the production and examination of plans and sections kept in pursuance of sections 20 or 21 of the Coal Mines Act, 1911, or sections 14 or 19 of the Metalliferous Mines Regulation Act, 1872, as are by those Acts conferred on inspectors, and those Acts shall apply accordingly.

Rights of Access of the Department of Scientific and Industrial Research to Underground Workings, etc.

The Department of Scientific and Industrial Research is concerned in the operation of the clauses of the Mining Industry Act (1926) set out above in two ways: (1) in connection with the work of the Geological Survey of Great Britain, and (2) in connection with its work on fuel research. Under the Act free access to journals of bores is given to officers of the Department of Scientific and Industrial Research, including the Geological Survey and Museum, and any others whom the Department may appoint for this purpose. The officers of the Department may take copies of the journals, may inspect the cores and other materials removed from the bores, shafts, mines and other workings, and may take representative specimens of rocks, fossils, minerals, etc., from these materials such as may seem necessary or desirable for the purposes of the Department. They have also right of access to workings and may take samples and have the same rights as to the production and examina- of plans and sections as the inspectors of mines.

The officers of the Department will carry papers of identification sufficient to establish that they are persons authorised.

Duties of Persons Sinking Boreholes or Shafts.

Apart from the power given to officers of the Department of Scientific and Industrial Research to visit workings and take samples (see above), Section 23 (1) of the Mining Industry Act (1926) places duties on any persons sinking a borehole or shaft. Their duties are:—

(i.) Notification of intention to sink a shaft or borehole.

(ii.) The keeping of a journal.

(iii.) The retention of specimens obtained of the strata passed through for a period of at least six months.

The notification required by the Act should be made before starting operations, and should be addressed to The Director, Geological Survey and Museum, 28, Jermyn Street, London, S.W. 1.

Persons responsible for sinking or boring operations should notify the Director of the Geological Survey and Museum in writing if they desire the information obtained from the shaft or borehole to be treated as confidential. Any officer of the Department visiting borings or shafts should also be warned if it is desired that the information should be kept confidential.

General Remarks.

As the object of the Department of Scientific and Industrial Research is to secure that the scientific information to be obtained from such borings, sinkings and other works should be collected in as accurate and complete a form as possible and rendered, when possible, available for general information in the service of the British mining industry, it may be advisable that repeated visits should be paid by the officers of the Department, and it is requested that, when desired, notification of the progress of the work or of any unforeseen developments should be sent to the Department to ensure that no valuable information should be lost. For this purpose it is hoped that the active co-operation of the persons undertaking the work will be extended to the officers of the Department.

Should the operations of boring or sinking be temporarily suspended through such causes as the loss of tools, caving, insertion of casing, flooding with water, etc., the Director, Geological Survey and Museum, would be greatly obliged if notice were sent him of the stoppage and of the resumption of work.

It will greatly facilitate the work of the Department and add to the completeness of the information obtained if the following requests are complied with.

Cores should be carefully laid out in regular order with marks at intervals showing depths of origin, and gaps in which the cores are absent or imperfect should be marked with an indication of the extent of the missing core and such fragmentary specimens as have been obtained at that depth should be retained in place.

The material obtained in sinkings should be laid out in order and the rocks from each depth should be kept together. If any band sunk through contains fossils all materials from that band should be kept together as these fossils may furnish important evidence of the geological horizon penetrated in the sinking.

It is specially requested that care be taken that the public should not be allowed to mix up the specimens obtained in boring or sinking so as to render it difficult to ascertain the depth from which specimens have been derived.

Any portions of cores which are of special interest (such as sections of coal seams), or are liable to disintegrate if exposed to rain and the action of the air (such as pyritous shales), might receive special attention to ensure their preservation.

October, 1926. H. Frank Heath, Secretary.

For the administration of the Act as regards boreholes and shafts the collection of data in England and Wales is managed by the Assistant-Director of the Geological Survey operating from London, and in Scotland (with Durham and Northumberland) by the Assistant-Director for Scotland, operating from Edinburgh.

Notification of a boring is acknowledged by the head office of the Geological Survey upon its receipt, and at a convenient time, by arrangement with the mining companies or boring firms, visits are made to the site of the boring or shaft for the purpose of measuring the cores and taking samples.

Two officers of the Geological Survey, one in England and one in Scotland, have been specially attached to the boring service. Their duties include the inspection of boreholes and shafts, the breaking up of the cores and collection of fossils and rock samples. In their respective offices they attend to the registration of the specimens and the filing of the records.

The fossils are subsequently examined and identified by palæontological specialists and the rocks classified by geologists familiar with the local stratigraphy.

When borings or shafts are being put down in areas within which a geological field unit is engaged, it is the duty of the members of the unit to keep in close touch with the operations.

The boring records are filed and numbered in relation to the quarter sheets of the six-inch scale Ordnance map, upon which the site and corresponding numbers are marked.

Graphic sections prepared by a geologist from the information provided by the log and the examination of the cores are made for every boring of importance and for all borings in mining fields where close correlation of the strata is necessary. The scale adopted is 40 ft. to 1 in. for some districts and 100 ft. to 1 in. for others.

All filed information is available for public reference except in the case of "confidential" boring records. The number of records relating to Scotland alone is now about 16,000.

So far as the boring and sinking clauses are concerned the Act of 1926 is being worked with the greatest smoothness. The principal advantage of the system is that there is now no danger of valuable information being lost; measurements can be checked and the cores can be examined before they have had time to deteriorate. Moreover, the information gained goes at once into the common pool of knowledge and the mining industry is appreciative of the opportunity of discussing its geological problems on the spot as they arise.

Boring for Water.

As the population increases in density in particular areas and the increase is accompanied by an ever-rising demand per head, the question of adequate water supply is one of the most pressing problems. This is intensified by the growth of vast industrial concentrations requiring large volumes of water for purely manufacturing purposes.

The Act of 1926, being a Mining Industry Act, it was not found possible to include in its boring clause any reference to borings for water. At present there is no authority for the compulsory notification of water borings. This is unfortunate, for the advantages derivable from accurate recording of the sites of water borings

and of the strata penetrated, together with the full particulars of the point of inflow, quantity, quality and rest-level of the water, are of the utmost importance to the community.

Nevertheless, much useful work is being done by the Geological Survey upon the old-established lines of close and friendly co-operation with water-boring firms and local water authorities. Most of the important firms now supply information regarding the borings they are putting down and the Geological Survey gives prompt advice in return. This relationship has developed greatly in recent years. The most recent information on the files of the Geological Survey relating to underground water supplies is available to all enquirers and as it grows in bulk it is published in the form of memoirs giving full details by counties. To date twenty-four such memoirs have been published and four others are in preparation.

A complete list of the publications of the Geological Survey (including economic memoirs, water supply memoirs, six-inch maps of the coalfields and of certain metalliferous regions, vertical and horizontal sections) is issued annually: the last issue being that on June 30, 1928.

Geophysical Work in Great Britain.

By W. F. P. McLintock, D.Sc., and James Phemister, M.A., D.Sc.*

(Geological Survey of Great Britain.)

Within recent years considerable interest has been aroused in physical methods of investigating sub-surface geological structure and a large amount of work has been carried out principally by commercial companies interested in the discovery of oil and minerals of economic value. The results of much of this work have, unfortunately, not been published, but sufficient has appeared in the literature to show that the various geophysical methods, gravitational, electric, magnetic and seismic are of considerable value in the detection and mapping of concealed structures, and not infrequently have materially helped in the selection of sites of trial borings and in the successful development of deposits of economic importance.

In order to obtain exact and reliable information regarding the applicability of some of the methods to the solution of definite geological problems the Director of the Geological Survey decided in 1927 to inaugurate a programme of geophysical work, the first part of which consisted of a series of tests of the gravitational method of survey by means of the Eötvös Torsion Balance. More recently investigations of the magnetic method have been commenced. In the present communication a résumé is given of the results so far obtained, most of which are either in the press or have already been published.

Gravitational Work.

The torsion balance as designed by Eötvös enables two elements of the gravitational field to be determined to an accuracy of 1×10^{-9} c.g.s. unit, these two elements being (1) the rate of variation in the intensity of gravity in the horizontal direction, the so-called gradient of gravity, and (2) a quantity proportional to the difference of curvature of the equipotential surface in the directions of greatest and least curvature, the so-called horizontal directing tendency, H. D. T., or curvature vector. When these two quantities have been determined at a number of stations in an area and the results, after correction for normal, terrain and topographic effects have been plotted on a map, it is sometimes possible to

* Communicated by permission of the Director, H.M. Geological Survey.

deduce the form and distribution of the underground mass producing the gravitational disturbance, and hence to arrive at conclusions regarding the geological structure.

The areas most suitable for gravitational surveys are characterised (1) by a moderately flat surface topography, slopes of over 5° being best avoided at least in the immediate vicinity of stations (2) by a geological structure or structures in which light and heavy rocks are brought into juxtaposition in such a way that the surface of separation between the light and heavy material is inclined to the horizontal. The structures to be investigated must not lie at too great a depth otherwise their gravitational effects are too small to be measured accurately, nor must the overburden (glacial drift or alluvium) concealing them show rapid variations in character or thickness. If the drift is highly irregular it may give rise to gravitational anomalies sufficiently large to obscure those due to the structure under investigation.

The method of survey employed depends on the type of structure to be investigated, and in this connection it is possible to divide geological structures roughly into two classes : (1) structures that can be essentially determined by a straight-line traverse across the strike, and (2) structures that demand observations at a network of stations to determine even approximately their shape and dimensions. The first class comprises anticlines, synclines, dykes, faults and lodes—in fact all structures whose length along their strike is very much greater than their breadth across it ; the second class includes domes, basins, igneous intrusions such as laccolites and volcanic necks whose length and breadth are comparable, unconformities, and buried topography with all its varied irregularities.

Dykes and lodes if of sufficient width and situated in areas of not too pronounced topographic relief are favourable structures for investigation, since they are usually steeply inclined to the horizontal and consist as a rule of material appreciably heavier than the country rock. Consequently they produce marked gravitational effects easily detectable by a traverse across their strike. In anticlinal structures older and usually heavier rocks are brought towards the surface in the core of the fold whilst the reverse applies to synclines. A traverse with the balance across the strike of such structures discloses the axis of the fold, and, if sufficient geological data are available, deductions may be made regarding the dip of the flanks of the fold and the depth of the surface separating the lighter from the heavier material.

The investigation of domes, basins, concealed volcanic necks, laccolites, subdrift topography demands observations at a network of stations. From the values and directions of the residual gradi-

ents so determined, isogams (=lines of equal gravity anomaly) may be constructed which give a rough idea of the conformation of the concealed structure. If the survey is sufficiently detailed, and if the geology of the area is well enough known to permit reasonable assumptions as to the specific gravity and thickness of the strata, it is usually possible to make fairly close estimates of the depth of definite gelogical horizons.

Three gravitational surveys have been completed by the Geological Survey, and full accounts of the methods, results and interpretation have been published.[1] In all cases problems were selected in areas where the geological elements were already fairly well known and where the results yielded by the torsion balance could be tested against the well-ascertained facts of geology. Two of the structures were of the type determinable by the method of traverse across the strike; the remaining one necessitated observations at a network of stations and the construction of isogams from the gradients for its determination.

The first and simplest test was made over the concealed outcrop of the well-known Swynnerton dyke at a place where the terrain was flat and where there was strong presumptive evidence of the existence of the dyke at no great depth. The country rock (Keuper Marl) is horizontal and has a specific gravity of 2·4, whilst the vertical or steeply dipping nepheline-basalt of the dyke has a specific gravity of 2·85–3·0. Observations at eighteen stations along a line at right angles to the presumed course of the dyke showed a gravitational anomaly qualitatively and quantitatively comparable with that yielded by a dyke 20 ft. wide, dipping westwards at 75°, whose top is 16 ft. from the surface. The results in this case were quite in accordance with geological prediction.

The second problem was the investigation of the course of a buried channel and the adjacent subdrift topography, partial details of which were already known from a series of borings put down in search of coal and ironstone. Problems of this nature are of great importance in Great Britain where the solid geology is obscured over large areas by a covering of drift of variable thickness. Sometimes the rock-surface underlying the drift is a highly irregular, preglacial topography consisting of buried channels and hills, and in mining and engineering operations a knowledge of such irregularities is highly important. In suitable areas the problem

[1] "A Gravitational Survey Over the Swynnerton Dyke, Yarnfield, Staffs." Summary of Progress for 1927, Part II., *Mem. Geol. Surv.*, 1928, pp. 1-16. "A Gravitational Survey over the Buried Kelvin Valley at Drumry, near Glasgow," *Trans. Roy. Soc. Ed.*, Vol. 46, Part I., No. 7, 1929, pp. 141-155. "A Gravitational Survey over the Pentland Fault, near Portobello, Midlothian Scotland." Summary of Progress for 1928, Part II., *Mem. Geol. Surv.*, 1929.

lends itself readily to solution by the torsion balance, for the rock masses underlying the drift have often a specific gravity of at least 0·5 greater than the sands and clays overlying them and they lie at depths that rarely exceed 300 feet and are usually considerably less.

The buried channel of the River Kelvin at Drumry, about seven miles west-north-west of Glasgow, has long been known from a series of borings which disclosed the presence not only of a drift-filled channel, 300 ft. deep, but also of a mass of rock rising abruptly through the drift to 74 ft. from the surface near Drumry. To the north of this rock-mass the channel was inferred to continue westwards for at least one mile, an inference based on an isolated record from workings one mile to the west of the area where the channel was more fully known.

A survey with the torsion balance disclosed the presence of the rock-mass which was shown to have a steep eastern face (slope about 10°), to be incised in places, and to extend westwards for a considerable distance. The inferred westward extension of the deep channel to the north of the rock-mass was shown to be non-existent, the balance results indicating clearly that the channel bends sharply to the south about half a mile to the north of Drumry and follows a southerly course from the bend. This survey fully demonstrated the usefulness of the torsion balance for mapping the features of subdrift topography and for supplementing and extending the information available from isolated borings.

The third survey was conducted over the line of a fault in carboniferous strata. The fault selected was the well-known Pentland Fault, in the Edinburgh district, which fractures the eastern limb of the Pentland Anticline and brings down the carboniferous limestone series of the Midlothian coal basin against the older rocks to the west. Along a great part of its course this fault can be traced by the juxtaposition of carboniferous with old red sandstone and older rocks, but towards the north-east end drift and raised beach deposits form an unbroken cover for over three miles and the trend of the fault is conjectural. Four traverses with the torsion balance were made across the inferred strike of the fault in this area in each one of which a pronounced gravitational anomaly was found. These anomalies were all of similar magnitude and when plotted on the map were found to lie along a line nearly parallel to the conjectured line of the fault and distant from it 180 yards to the east. Calculations show that the anomaly is due to a steeply inclined reversed fault heading towards the west and bringing up on that side the well-known volcanic horizon of the Arthur's Seat lavas to within 150 ft. from the surface. The thickness of this series of heavy basic lavas is estimated as about

600 ft. It was also found possible in the course of this survey to detect heavy bands of limestone in a highly inclined series of sediments and to deduce the strike of the rocks from the balance results.

The experience of the Geological Survey with the Eötvös Torsion Balance has shown that the method is of considerable value in geological investigation. In suitable areas where the main features have already been determined by geological survey the balance may be of the greatest use in extending, detailing, and even correcting previous geological inferences. When the shape, dimensions and relative density of an underground mass are known it is usually possible to calculate the gradients at points on the surface over the mass; the reverse operation, namely, to calculate the shape, position and relative density of a body from the values yielded by the balance is a much more difficult problem and can only be accomplished if a large amount of geological information is available. Consequently the method is most usefully employed, as instanced above, in areas where geological data are available to guide and control the gravitational interpretation of the structures causing the anomalies.

Magnetic Work.

The detection of local variations in the earth's magnetic field is perhaps one of the oldest and best known methods of prospecting for underground masses differing in magnetic permeability from the surrounding material. In recent years field work has been facilitated by the improvements effected in the appropriate instruments, and during the present year the Geological Survey acquired field balances of the vertical and horizontal type as designed by Schmidt and manufactured by the Askania Company, Berlin. The first field test was carried out by Mr. A. F. Hallimond, of the Geological Survey, over the Swynnerton Dyke, a structure previously investigated with the torsion balance (see above). The vertical field balance alone was suitable for this survey and by its means the concealed course of the dyke was mapped for a distance of two miles. A series of observations taken along the line of the torsion balance survey yielded magnetic results in substantial agreement with the gravitational ones, but other traverses south of that line show that they dyke splits into two or more separate members—a result to be anticipated from the available geological evidence. A complete account of this magnetic survey is in the press.[2]

Further work is now in hand in the Melton Mowbray district, Leicestershire, where a marked magnetic anomaly is known to exist. The results so far obtained are promising but they are not sufficiently advanced for publication.

[2] "Magnetic Observations on the Swynnerton Dyke," *Mining Mag.*, 1929.

Under suitable conditions the magnetic is much quicker than the gravitational method, since it involves neither the bulky apparatus nor the cumbrous technique of the latter. Quantitative interpretation of magnetic data is, in some cases, rather uncertain on account of variability in the degree of magnetisation of the disturbing mass causing the effects, irregularity of its boundaries, instrumental errors and so on. As in the case of the gravitational method, geological data are necessary to control and guide conclusions based on the observations.

Other Geophysical Methods.

There are no published records of seismic or electrical surveys in this country although it is known that such work has been and is being carried out by private companies. A committee, entitled the Geophysical Research Committee, has recently been appointed by the Department of Scientific and Industrial Research for the purpose of encouraging and developing research in the various methods which, as seems certain, will become of increasing importance in geological investigations.

Summary.

An account is given of the geophysical work so far carried out by the Geological Survey of Great Britain. Gravitational Surveys with the Eötvös Torsion Balance are described, the structures investigated being respectively a dyke of basic igneous rock intrusive into marls, a buried channel and the associated preglacial topography, and a fault in carboniferous strata. Magnetic measurements over a dyke of basic igneous rock are described.

The Mintrop Seismic Method.

By Ernest H. Neville

(Geophysical Company, Ltd.).

The several methods of Geophysics have been applied for the last ten years, and are now recognised throughout the world as being of inestimable value and giving valuable assistance to those interested in the exploitation of oil and mineral bearing lands.

The most important methods used are Gravimetric, Seismic, Electric, Magnetic, Radioactive and Geothermic.

Valuable information can be obtained from a Geophysical examination of an area, by the application of one, or a combination, of such methods, previous to the selection of sites for boreholes and shafts.

Ore bodies, salt domes, anticlines, synclines and faults can be located and outlined.

As so much has already been written concerning the Gravimetric and Electric methods, this paper is confined to the Seismic Method. The important advantage of the application of the Seismic Method is that it provides a means of determining, with close approximation, the depth at which underground beds are to be found. But each of the other methods has its own part to play when the prevailing conditions render their use advisable.

By means of the Seismic method the depths of subsurface geological features are determined—a matter of great importance to the Mining Engineer and the Driller, as they can, with this knowledge, select the suitable type of derrick and the appropriate diameter for the proposed shaft or well.

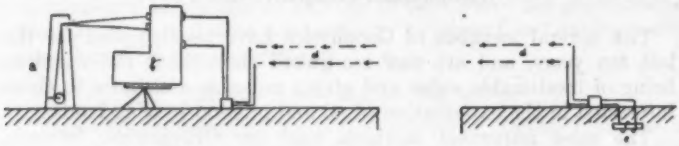
A brief summary of the principles and application of this method, as developed by Professor Dr. L. Mintrop, is given below:

The method is based on the fact that rocks with different elasticity or density transmit mechanical and acoustic waves with different velocities. The velocity—*i.e.*, the travelling speed—in various strata differs from a few hundred yards per second in loose sands to more than 7000 yards per second in very hard and compact or crystalline rocks.

A number of small and transportable seismographs are placed along a straight line, a charge is exploded at one end of the line and the seismic waves proceeding from the resultant artificial earthquake shocks are recorded by the seismographs.

Fig. 1 shows the arrangement of the instruments used for such a reception.

Each Seismograph is combined with a photographic recording apparatus containing an electric lamp and a drum of photographic paper, which travels round or from the drum at a definite speed, means being provided by a pendulum, of known frequency, in the recording apparatus by which recording marks at equal time intervals are made upon the photographic paper. The vibrations

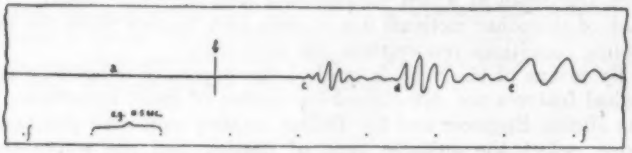


(*a*) Seismograph.
(*b*) Photographic recording apparatus.
(*c*) Charge.
(*d*) Wireless.

FIG. 1.

which read the seismograph are registered on the paper by means of a reflected beam of light. The exact moment of explosion is also recorded on the same photographic paper by the interruption of an electric circuit, the effect of which is transmitted either by wire or by wireless (see Fig. 1).

A number of such seismograph records known as "seismograms" are obtained from each explosion. A sketch of such a seismogram is given in Fig. 2.



(*a*) No vibration of seismograph before arrival of shock.
(*b*) Moment of explosion.
(*c*, *d*, *e*) Oscillations of seismograph produced by the shock.
(*f*) Time-marks.

FIG. 2.

The time which has elapsed between the initial mark "b" (see Fig. 2) and the appearance of the first oscillation "c" is called the "travelling time" of the elastic wave. A number of subsequent waves or oscillations due to the same shock are also recorded on the seismogram and each has its specific meaning.

For the present explanation it is sufficient to regard only the first sharply defined wave "c" (see Fig. 2).

The travelling time "t" of this first vibration thus recorded represents the time taken by the wave to travel by the quickest route from the point of origin to the seismograph.

This time will be increased if the seismograph is removed further from the origin of the shock, since the travelling time increases proportionately to the distance. Such travelling times and respective distances are shown by a diagram or "graph" in which the ordinates represent the travelling times and the abscissæ the distances between the explosion point and the observation stations of the seismographs.

In ground without changes of the petrological conditions, a straight travelling time-curve will be obtained—*i.e.*, the speed of the waves will be constant and therefore from shocks produced at the distances e1, e2, e3, e4, e5 and e6 the travelling times t1, t2, t3, t4, t5 and t6 will be respectively observed.

So far reference has only been made to the case of a more or less homogeneous medium without a change of elasticity or density, but should there be a sudden change in the formations, for instance, limestone underneath sand or clay, the time curve will show quite a different and very distinct character than that described above. The travelling speed, instead of being constant, increases abruptly from the point at which the elastic waves, formerly travelling in loose sand, enter the highly elastic limestone. At that point the time curve suddenly shows a sharp change of direction (see "b" in Fig. 3). The distance at which the sudden change occurs is shown marked "d."

Thus in the example given in Fig. 3, at the distance e3, e4, e5 and e6 the first vibration will not arrive at the times t3, t4, t5 and t6, but at the times tx3, tx4, tx5, tx6. The distance "d" at which the sudden change in the direction of the time curve occurs, is the indication of the depth of the more elastic stratum below, for it is clear that this change will occur at a shorter distance from the zero point (representing the place and time of the explosion) the nearer the more elastic formation is to the surface, and at a longer distance, the deeper the more elastic formation is from the surface.

Whilst the speed derived from the first part of the time curve shows the travelling speed in the upper loose stratum, the portion of the curve following the change of direction gives an indication of the propagation speed in the lower more elastic stratum.

In cases where there are several formations following each other with more or less abrupt changes of density and elasticity, the time-curve will show several changes of direction, the distances of which from the zero point will depend on the respective depths of such formations and the relation between the respective travelling speeds of the waves.

The calculation of such depths is carried out by formulæ well known to those who are acquainted with seismological science.

The speeds of the waves in all kinds of rocks are known to the geophysicist, and he can from the time-curve, not only calculate the depths of the more elastic formations underneath a loose overburden, but from the observed speed of the waves taken from the time curve, he will also obtain information about the petrological character of the hidden formations.

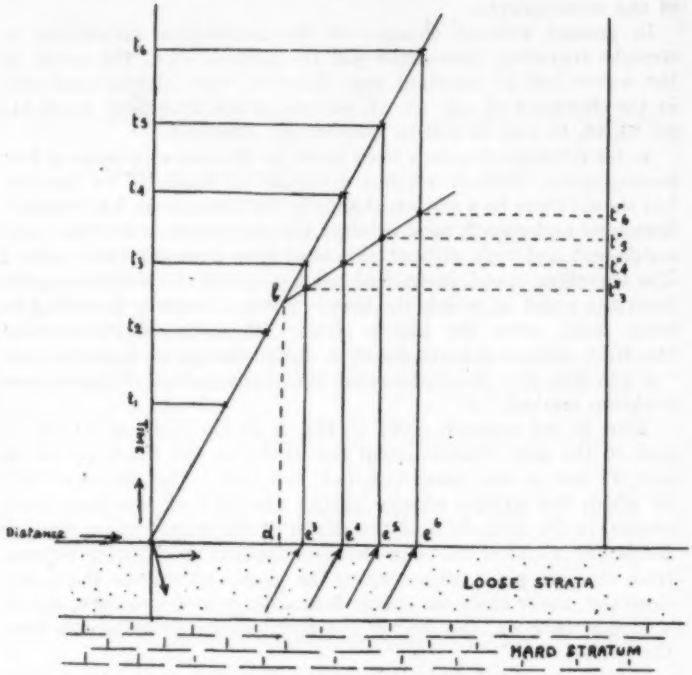


FIG. 3.

Furthermore, upward or downward inclinations of the rocks, faults and displacements, swallow-holes and other irregularities in the lower formations have all characteristic effects on the time-curves; for they directly affect the travelling times of the waves and result in distinct types of diagrams. In each case a correct geological interpretation can be arrived at by a suitable system of observation lines and observation points selected by geophysicists and geologists in co-operation with one another.

Great successes in many parts of the world have been achieved

by the Seismic method and the following may be cited as typical examples, viz. : Some 60 salt domes have been discovered in Texas and Louisiana, limestone anticlines and granite ridges have been located in the Near East, whilst faults, synclines and other tectonic features have been determined in coal iron-ore districts.

One of the most striking applications was the accurate contouring of the surface of the Palæozoic rocks beneath the later looser strata in Holland.

Drilling on the Gold Coast, West Africa.

By O. A. L. Whitelaw, F.G.S., F.R.G.S., M.Inst.M.M.
(Gold Coast Geological Survey).

Brief History.

The discovery and use of gold on the Gold Coast (Côte d'Or of the French) must be of great antiquity. The exploitation began early enough to be noticed by Herodotus, the oldest of Greek prose-writers. He tells us that the Carthaginians received gold from a black people, whose caravans crossed the Sahara, or Great Desert, and that they traded for it with the wild tribes of the West Coast. His words are as follow :—

"There is a land in Libya, and a nation beyond the pillars of Hercules (the Straits of Gibraltar) which they (the Carthaginians) are wont to visit, where they no sooner arrive but forthwith they break cargo; and, having disposed of their wares in an orderly way along the beach, leave them, and, returning aboard their ships raise a great smoke. The natives, when they see the smoke, come down to the shore, and laying out to view so much gold as they think the worth of the wares, withdraw themselves afar. The Carthaginians upon this come ashore and look. If they deem the gold sufficient they take it and wend their way; but if it does not seem to them sufficient, they go aboard once more and wait patiently. Then the others draw near and add to their gold till the Carthaginians are content. Neither party deals unfairly by the other, for they themselves never touch the gold till it comes up to the worth of their goods, nor do the natives ever carry off the goods till the gold is taken away."[1]

"The classical trade in gold and slaves was diligently prosecuted by the Arabs or Saracens after Mahommet's day. In due time the Moroccoan Arabs were succeeded by their doughty rivals the Portuguese of the heroic ages of D. D. Joao II. and Manoel. In 1470 Joao Santarem and Pero d'Escobar, Knights of the King, sailed past Cape Palmas . . . , and on their return homewards found a trade in gold-dust at the village of Sama (Chamah) and on the site which we miscall Elmina. . . . Thus Portugal secured to herself the treasures which made her the wealthiest of European Kingdoms. But when she became a province of Spain under D. Phillip, her eastern conquests were systematically neglected in favour of the Castilian colonies which studded the New World. The weak Lusitanian garrisons were massacred on the Gold Coast as in other parts of Africa; and the Hollanders, who had conquered their independence from Spain, proceeded to absorb the richest possessions of their quondam rivals. Elmina, the capital, fell into Dutch hands (1637) and till 1868 Holland retained her forts and factories in the Gold Coast.

"In their turn the English and the French . . . began to claim their share and until the mineral discoveries of California and Australia the Gold Coast continued to be the principal source of supply to the civilized world."[2]

"The Ashanti war of 1873–74 had the effect of opening to transit a large area of workable ground. English officers traversed the interior in all directions and their reports throw vivid light upon the position, the extent, and the value

[1] "To the Gold Coast for Gold," Burton et Cameron, Vol. II. (Chatto et Windus, London, 1883).
[2] Ibid., pp. 338–346.

FIG. 1.

MAP OF THE GOLD COAST—SHOWING POSITION OF DRILLED AREAS.

of the auriferous grounds which subtend the Gold Coast, and which supply it with the precious metal." [3]

During the late seventies there was greatly increased activity in the development of the mineral resources. Numerous concessions were obtained from the ruling Chiefs, and the old native workings were reopened and explored to greater depths. In this respect the names of the house of Swanzy, and of a Frenchman, M. M. J. Bonnat, are constantly in evidence. Of the latter it is said:—

"He was a bright cheery little Frenchman of great energy, some knowledge of Fanti, or rather Ashanti, language, and perfect knowledge of the native character . . . he soon became agent to some small trading firm, and then pushed his way high up the unexplored Volta River. Here the Ashantis barred his passage and eventually took him prisoner as he attempted to cross their limits: he was carried to Kumasi where he remained in confinement for three years. When the war of 1873—74 set him at liberty he passed through Wâsâ (Wassaw) to Europe and by his local information, and that gathered in captivity, he secured the public ear for the Gold Mines." [4]

It was in 1877 that Bonnat in company with General Wray proceeded to Tarkwa where the natives were reported to be obtaining rich gold. In a report M. Bonnat states:—

"There are at present here 1306 natives working at the Tarquah mines, and the number is increasing every day. This has been a very profitable year for them, but their galleries are getting very deep." [5]

These native workings were concentrated around the site of the present Taquah shaft. They were reserved for the natives and a lease of the land surrounding them was taken up by a French company. The natives continued to work their reservation for some years until stopped more by water than exhaustion of the ground. Eventually the *enclave* was taken over by the French.[6] This situation eventually proved to contain the richest gold-ore on the field.

It was not until two or three years had elapsed that the nature of the gold-bearing material being worked was recognised as coarse hæmatite-bearing grits and conglomerates forming portion of a very old series of sediments. On the discovery of the Witwatersrand mining field some years later these auriferous conglomerates received the general name of "Banket," the term being adopted on this field. This "Banket" was traced N.E. and S.W. for many miles and numerous concessions obtained.

Following the completion of the railway line to Tarkwa (which was started at Sekondi in August, 1898, took over three years to reach Tarkwa, and arrived at Kumasi in October, 1903), diamond drilling was extensively carried out by the various companies and

[3] Ibid., pp. 347-348.
[4] Ibid., p. 298.
[5] "The Geological and Mining Features of the Tarkwa-Abosso Gold Field," by O. A. L. Whitelaw. (Memoir No. 1. p. 1, Gold Coast Geological Survey.)
[6] Ibid.

the banket located down to a depth of 2000 ft. Reports were obtained from capable mining engineers and geologists with experience of the Witwatersrand goldfield. These reports, the chief of which are those published by A. R. Sawyer,[7] S. J. Truscott,[8] and B. I. Collings,[9] elucidate the various complexities of faulting and folding of the banket beds, and established their analogy with the conglomerates of the Rand goldfield of South Africa.

Following drilling operations, the various mines were increased in depth. Old machinery was replaced by modern steam, air and electric plants, and the most modern types of crushing and metallurgical mills erected.

During their period of work the various mines have yielded over £18,000,000 worth of gold. The two remaining working mines, the Abbontiakoon and the Abosso, are nearing a depth of 2000 ft., which is not far short of the greatest depth at which the banket was cut by drilling on the Fanti Mine in No. 6 bore— viz., 2372 ft.

Apollonia.

The occurrence of bitumen and pools of oil in the coastal area lying between the Twin River and the French Ivory Coast boundary were probably well known to the natives, and regarded as "fetish" by them. Its existence is referred to by Burton and Cameron[10] in 1882, thus :—

> "Mr. Grant presently returned from his excursion to the West. . . . I had warned him to look out for, and he succeeded in finding, beds of bitumen permeated with petroleum : this material will prove valuable for fuel and for asphalting, if not for sale."

A concession was taken over this area by the Société Française de Petrole, who in 1895—97 sank a series of five boreholes to a maximum depth of 800 ft. near the village of Bokakra. The records of these drillings are not available.

The United Africa Company, Ltd., took over concessions extending over 125 square miles of this area. Drilling commenced in April, 1923, and was carried on until April, 1925. Two wells were put down : No. 1 (Bonyere) at 3 miles from the coast line, and No. 2 (Takinta) at 3½ miles from the coast line. These wells are 4½ miles apart, the maximum depth reached being 4,005 ft.

Geological examinations and reports were made by Major A. D. Lumb, M.C., and his staff on behalf of the United Africa Company, Ltd., and in 1921 the area was visited by the Director of the Geo-

[7] "The Tarkwa Goldfield, Gold Coast, West Africa," Trans. Inst. Mining Engineers, Oct. 3rd, 1901.
[8] "The Banket of the Tarkwa Goldfield, West Africa."
[9] "Geological Report on the Tarkwa and Prestea Goldfield," July 20th, 1909.
[10] "To the Gold Coast for Gold," Vol. II., p. 307.

logical Survey of the Gold Coast[11] and a report made to the Governor.

Early in 1928 a fuller examination was made by Major N. R. Junner, M.C., geologist to the Geological Survey, and a report made to the Director on May 28th, 1928.[12]

The Tarkwaian System (Age unknown).[12]

"The type locality of these rocks is the Tarkwa-Abosso Goldfield. There they consist of a series of coarse and fine sediments, grouped by Mr. Whitelaw[14] into five main divisions, in descending order, conformable sequence and thickness, as follows:—

5. Dompim Quartzites, 1,000 ft.
4. Dompim Phyllites, 500 ft.
3. Huni Sandstones, 1,500 ft.
2. Tarkwa Phyllites, 800 ft. to 1,000 ft.
1. Banket Series, 2,100 ft. of which 1,500 ft. are between the Kawere Conglomerate and the Main banket.

"The basal bed, the Kawere Conglomerate, is of fair but unknown thickness, and is composed of large pebbles, almost wholly of decayed rocks, probably andesites. Overlying it is a succession of hæmatite-sandstones and quartzites, sericitic grits, breccia-conglomerates and conglomerates. Some of the last-named are auriferous, similar in many respects to the banket of the Witwatersrand, Transvaal.

"The Tarkwa phyllites, with and without chloritoid, include flagstones, and are mainly greenish-grey in colour.

"At Tarkwa these two series occur as a syncline with a N.E.—S.W. strike. Intrusive into the upper portion of these sediments are considerable masses of epidiorite (silicified gabbro?) with large dykes of altered dolerite and diabase, and small ones of quartz-porphyry."

Since these sediments contain no fossils nor are they associated with other fossiliferous beds, their age is unknown.

The gold zone is confined to the upper part of the hæmatite-bearing arenaceous series at an average depth of between 500 and 600 ft. below the base of the Tarkwa phyllites. The productive portion is confined to the quartz-hæmatite-conglomerates. These vary in thickness from a few inches to 20 or 30 ft. Their values are erratic, and in different mines may be found on opposing walls, or in a section of the centre of the conglomerate where it is separated by a quartzite band. The operating companies endeavour to extract ore of a value of 8 dwts. or over per ton.

The junction of the arenaceous banket-bearing series with the overlying argillaceous beds (Tarkwa phyllites) has caused a physiographic break which can be traced throughout the field. This

[11] Report on the Geological Survey for 1921, by the Director, Mr. (now Sir) A. E. Kitson, C.M.G., C.B.E., etc.

[12] Major N. R. Junner, M.C., D.Sc., D.I.C., etc., now Director, Geological Survey of Sierra Leone.

[13] Bulletin No. 2 of the Gold Coast Geological Survey, by Sir A. E. Kitson

[14] The Tarkwa-Abosso Goldfield, Memoir No. 1, Gold Coast Geological Survey.

is an important point, affecting any future boring operations, as this position can be utilized for directing the drill towards the banket at, or near, a right-angle to the dip of the beds, thus cutting the banket at some 500 to 600 ft. from the surface.

The normal dip of the banket is about 30°, but this has been increased at the Taquah Central Mine to 50° ; and at Adjah Bippo Mine to 80°, in consequence of local faulting.

The phyllitic beds are easily bored, and the arenaceous series, despite their hardness to the hammer, are mixed with a fair amount of dolomitic and micaceous material which cuts fairly well. The dykes and igneous sills contain considerable hornblende, and cut fairly readily although extremely tenacious to the hammer. Quartz veins, and elongated pebbles in the conglomerates, offer the greatest resistance to the drill.

The Apollonian System. (Cretaceous ?)

These beds occupy the coastal area stretching from Ampien at the mouth of the Twin River westward to the Tano River on the Ivory Coast boundary, and northward to Nuba on the Tanoso to Enchi Road. They probably extend for some distance into the French possessions.

The first official report upon the geology of the area was made by the Director of the Gold Coast Geological Survey (Sir Albert E. Kitson, C.M.G., C.B.E.) when he visited the locality in 1921. In his report [15] he, *inter alia*, states :—

"From the Ankobra River westward to the boundary of the Ivory Coast, a distance of 60 miles, the whole of the shore line consists of sand, the seaward fringe of which is firm. . . . Low-lying swampy country with lagoons lies behind Atuabo and Beyin. To the west of Kangan, and close to it, are two prominent hills upwards of 100 ft. high. One stands at about a quarter of a mile from the shore, the other at about half a mile further inland. They are covered with dense scrub. Pieces of very ferriferous sandstone and impure limonite occur on the surface of the former. They have the appearance rather of iron-cemented sand than of bedded sandstone. Viewed from the top of this hill the country to the north-east and east shows as a deep bay of low ground, backed in the distance by high ground. . . . At Allegonzuri a low bank at high-water level consists of a deposit of plastic clay containing a good deal of pyrite. This is overlain by beach sand.

"The Domini lagoon consists of a mangrove swamp with open patches covered with swamp grasses and reeds. Through it tidal waters flow in several streams. The bed of the swamp consists of a sandy peat, several feet thick formed of the decayed swamp vegetation. Several blocks of compact sandy peat, probably derived from the swamp, were found lying in the sand within tidal limits, between the mouth of the lagoon and Bonyere.

"Bordering the lagoon on its northern side there is a low, nearly flat, area of loose sand. In this locality several bores were sunk some years ago by the Société Française de Petrole. In one of these bores heavy oil can be seen in the stand-pipe. In another, similar oil shows at a depth of about 15 ft. in the pipe. A short distance from this place a thick coating of heavy oil

[15] Report on the Geological Survey for the year 1921.

occurs on the surface of a small stream, where a log crosses it forming a small pool (Fig. 2). Within a few feet of this spot a strong spring of water with large bubbles of gas, rises to the surface of that stream. Similar bubbles of gas rise through the pool. . . . Where the strong spring rises to the surface there appears to be a very thin film of oil discharged at irregular intervals: it probably comes up with the gas bubbles. No oil was noticed in the stream above that point There is a bore hole on the opposite side of it, a few yards from the pool. It is said to have proved no oil. Some heavy oil floats on the surface of another small stream also in this locality. No fossils were visible in the sand around the bore hole. . . . Shafts were sunk at various places in the Kangan and Allegonzuri localities to attempt to prove the character and thickness of the clays and limestones, but owing to quicksand and water none reached a depth of more than 26 ft. The evidence obtained from these shafts and from field observations shows that the fossiliferous limestone is not a continuous bed, but merely a string of disconnected lenticles, embedded in fossiliferous clay, or lying on it.

"So far as proved the clays vary in thickness from 5 to about 10 ft., and in colour from a medium bluish grey to a very dark grey. At some places they are highly fossiliferous, containing numerous shells of bivalves. . . . The determinations of the fossils, should they include characteristic zonal species, would show the age of the beds. Should they prove to be of Tertiary age the prospects of finding deposits of oil and limestone of commercial value would be much improved. On our return to England these fossils will be handed to an eminent palæontologist for examination." (These fossils were kindly examined by Professor A. Morley Davies, who regarded them as of Jurassic or Cretaceous age.) [16]

"Small exposures of sand impregnated with bitumen were seen at several places in Western Apollonia, and bitumen is recorded from the surface sand in a borehole near Eboinda in the Ivory Coast near its boundary. Heavy oil undoubtedly occurs in the Bonyere district.

"Whether these are evidences (*a*) that oil has reached the surface along a line of fracture from deposits underlying at great depth, or (*b*) that small supplies of oil were formed in the recent beds from decomposing swamp vegetation is a question which cannot be settled, if at all, otherwise than by boring at many places. The cost of such boring would be great, but both from economic and scientific points of view it is desirable that it should be done, though only after a careful geological examination of the country already indicated."

A further examination of the area being drilled was made by Major Junner, early in 1924, and a report submitted to the Director of the Geological Survey.

Abridged Report by Major Junner.

At favourable points, e.g., the contact of a limestone bed with the underlying clay or the contact of an oil-sand with the overlying clay, three or more shallow boreholes were sunk and logs of the beds passed through were made. The elevations of the collars of these boreholes were accurately determined by Dumpy level, and their relative positions were fixed by survey. The amount and direction of dip were then determined by graphical solution

[16] Provisional Geological Map of the Gold Coast and Western Togoland with brief Descriptive Notes thereon, by the Director, Sir A. E. Kitson, p.11.

of a three-point problem. From the dips so determined, and from a comparison of the reduced levels of the outcrops of the limestone and oil-sand, it appeared there was a domed anticlinal axis extending in a direction roughly E.S.E. to W.N.W. from near Nawuli to near Edduaso. This axis corresponds closely to a prominent ridge which reaches an elevation of above 300 ft. near No. 1 Camp, Nawuli.

The sites for the boreholes were chosen approximately on the crests of two apparent domes on this anticline, one west of Nawuli [No. 1 Nawuli (eastern bore)], and the other N.E. of Takinta [No. 2 Takinta (western bore)].

The drill used for boring was of the rotary type . . . using mud fluid (a mixture of clay and water) pumped under pressure to seal up the hole to prevent caving of unconsolidated sand, etc. In soft beds where the progress of drilling is rapid, and particularly at night, it is possible to seal off small shows of oil and gas before being observed. A core barrel attachment was used for taking samples of core from the bottom of each hole : no other cores were obtained.

A study of the logs and the corresponding samples from the two boreholes shows that the rocks penetrated are entirely sediments. They consist essentially of rapidly alternating sands and clays with occasional thin bands of fossiliferous limestone and gravel. In depth the sands and clays become more consolidated and give place to sandstones, clay-shales and sandy shales which often contain a fair amount of muscovite.

Nodules of marcasite are common, particularly in the clays and clay-shales. Concentrates obtained from the sandy shale from near the bottom of each hole show the presence of a good deal of marcasite, and in addition, a little garnet, staurolite and zircon, but no gold. The lighter portions consisted of small rounded pebbles of vein-quartz, small grains of granitic quartz, and muscovite. From the concentrate from near the bottom of No. 1 borehole near Nawuli one small well-cleaved crystal of felspar or corundum was obtained.

The core sample taken from near the bottom of No. 1 hole (Nawuli) at a depth of 3,330 ft. consists of light grey porous sandy micaceous shale, containing occasional casts of small shells and a little bituminous matter. The core sample from the bottom of No. 2 hole near Takinta came from a depth of 3,005 ft. and consists of light grey slightly sandy micaceous shale.

The limestones contain abundant marine fossils and the associated clays contain marine shells. Certain clays contain carbonized

plant remains. The carbonized plant remains were not seen in any of the bore samples, but occur in the clays outcropping at the surface in several places. With the exception of the fossils in the limestones, and in the core from the bottom of No. 1 hole (Nawuli), no fossils were recognized in the bore sample, but this was expected owing to the method of drilling.

As a whole the deposits passed through are essentially of shallow-water origin, and are probably for the most part deltaic in character with subordinate shallow water, marine and estuarine types.

Although the bores are about four miles apart a comparison of the logs shows that there is, at least to a depth of 1,000 ft., a broad parallelism between the sections of the strata pierced.

The upper limestones and clays form a definite horizon, and other conspicuous beds are the sands from about 360 ft. to 520 ft., the limestones and clays from 520 ft. to about 620 ft., the 100 ft. bed of sand immediately underlying these limestones and clays, and the succeeding limestones and clays. Below 1000 ft. the parallelism between the two sections is not nearly so well marked.

The following table shows the change in character in the beds passed through in No. 2 bore (Takinta (western bore)) from the surface to 3,005 ft.

0–990 feet.

530 feet.—Sands.
327 feet.—Clays, clay-shale and calcareous shale.
79 feet.—Limestone.
54 feet.—Sandy shale.

990–1,990 feet.

472 feet.—Clays, clay-shale and calcareous shale.
173 feet.—Sandy shale.
134 feet.—Sands and sandstone + 55 ft. (?) limestone or sandstone.
137 feet.—Limestone.
23 feet.—Coarse gravels.
11 feet.—Shale and gravel.

1,990–3,005 feet.

600 feet.—Sandy shale.
274 feet.—Clay-shale.
82 feet.—Sands and sandstone.
38 feet.—Limestone.
20 feet.—Shale and gravel.

The following extracts from the logs of the bores show the depths at which oil and gas zones were struck.

No. 1 Borehole near Nawuli (Eastern Bore).

At 55-82 feet. Traces of heavy oil were noted in sandy shale (clay with lenses of sand). This is the "oil-sand" which outcrops in several places in this district and is used as a key-bed.

FIG. 2.

OIL-BEARING SPRING OF WATER AT BONYERE, GOLD COAST.
(THE THICKNESS OF THE OIL IS INDICATED BY THE DARK MARK ON THE STICK.)

FIG. 3.

NATIONAL BOILER AND HOLT TRACTOR OPERATING IN APPOLONIA. (WOOD FUEL USED SEEN IN FOREGROUND.)

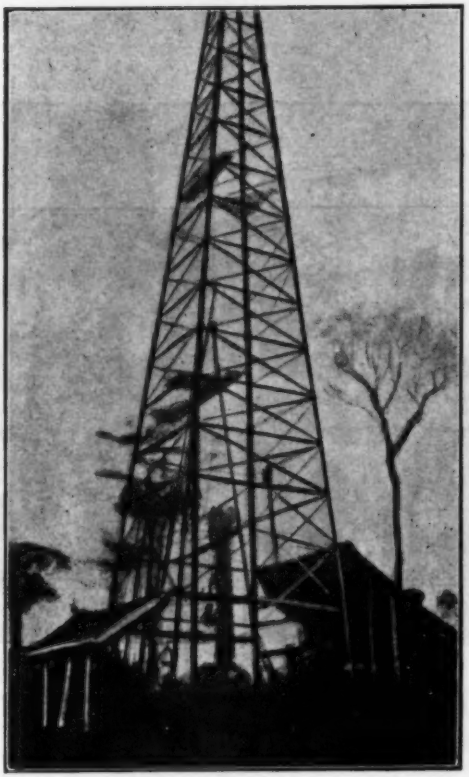
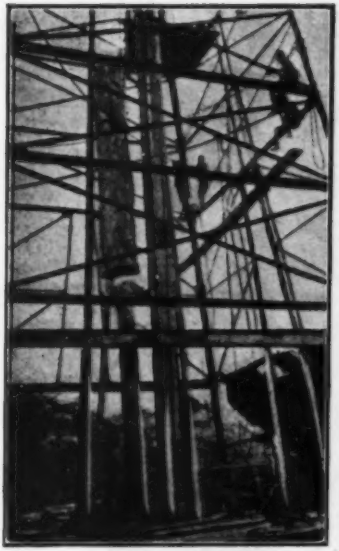
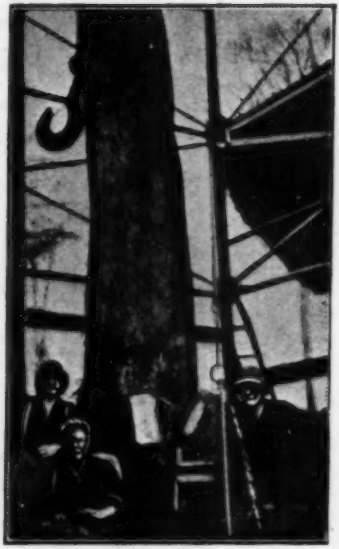


FIG. 4.

CABLE TOOL DERRICK AND DRILL, APPOLONIA.



DRIVING PIPE ON ROTARY RIG, APPOLONIA.



DRIVING 15½-INCH CASING WITH A TREE. APPOLONIA.

FIG. 5.

265– 290 feet.—Light (small ?) gas show in coarse sand.
334– 344 feet.—Light gas show in coarse sand.
369– 463 feet.—Shows of gas in coarse sand.
471– 491 feet.—Shows of gas in sand.
1,192–1,226 feet.—Sandy shale containing traces of oil.
1,400 feet.—Show of gas in sandy shale.
1,800 feet.—Show of gas in very hard sandy shale.
2,400 feet.—Show of gas in coarse sandy shale.
2,650–2,683 feet.—Good show of gas in sandy shale.
3,000 feet.—Show of light oil in mud shale (?).
330 feet.—Good show of gas in grey sand.

An accident to the crown pulley when at a depth of about 3,335 ft. prevented this hole being continued at the time to a greater depth The boring rig is still standing and the hole can be continued if desired.

No. 2 Borehole near Takinta.

118– 126 feet.—Little oil and gas in black clay.
1,016–1,019 feet.—Show of gas in sand.
1,443–1,490 feet.—Traces of oil in shale containing streaks of sand.

This hole was abandoned at 3,005 ft. and filled with mud and the boring rig dismantled.

Oil Drilling in Apollonia.

Oil drilling in Apollonia was started in 1923 by the African and Eastern Trade Corporation (now the United Africa Company, Ltd.). The National Supply Corporation provided the drilling equipment for this work, consisting of two complete outfits for drilling by the rotary system each of which included a 120-ft. steel derrick, 20 inches diameter Rotary machine, two-speed draw works and all rotary drilling pipes, casing, fishing tools and necessary equipment for operating in new territory far removed from any base of supply and without facilities for effecting repairs or replacements which might be necessary.

The whole undertaking illustrated in a very remarkable manner the difficulties attendant on oil exploitation in virgin territory where work of the same kind had not previously been seriously attempted. The African and Eastern Trade Corporation undertook the enterprise on very sound lines, securing detailed examinations and reports from Major Lumb and his assistants before the commencement of operations, and acquiring what was at that time the most efficient and up-to-date machinery for the purpose. All material was ordered from the United States, and was shipped from New York towards the end of 1922. Difficulties were experienced as early as the landing of the material in West Africa owing to the absence of sheltered harbours, and all the material had to be discharged from the steamers overside into surf-boats about two

miles from land. Every item of the equipment had to be conveyed by native labour on surf-boats to the beach and in this transportation certain items were unavoidably lost overboard through the capsizing of the surf-boats, etc. Among articles which were thus lost were certain parts of one of the derricks which had to be replaced and naturally caused some delay in the commencement of operations.

Certain items of the equipment involved large heavy pieces which presented considerable difficulties, though many of the larger items were dismantled into packages of a size and weight which could be handled with the facilities available at the West African coast. It was, of course, impossible to make any reduction in the size of the boilers, of which four were supplied, each of 50 h.p., weighing between 5 and 6 tons each (Fig. 3). The boilers were thoroughly prepared prior to despatch from New York by having all openings plugged with flanges, so that they would float in the sea, and were tested in New York Harbour before being shipped. On arrival at West Africa they were lowered overboard from the steamers and floated ashore without any mishap, and the subsequent drilling operations showed that the boilers had suffered no damage whatever through the method of handling.

Six experienced rotary drillers, with one head-driller, were engaged in the United States and arrived in West Africa at the same time as the material was landed and in May, 1923, the first derrick was erected and most of the machinery installed on the first well at Ahovere (Fig. 4).

The second well was located some 4½ miles away at Bonyere, the derricks being erected and machinery being installed in remarkably good time considering the difficulties of transport and labour conditions in the country.

Transportation of the material from the beach to the drilling sites presented considerable difficulties. Most of the transportation was undertaken by a 5-ton caterpillar tractor and trailer which was driven most of the time by the head-driller, owing to the lack of any other competent operator. This machine was very severely used, but the haulage of material was rapidly completed, 180 tons of equipment being moved a distance of four miles in five days. In many cases loads of 4½ tons were taken on each trip, which in consideration of the absence of roads, climatic conditions, etc., speaks very well of the tractor.

Drilling of the first well was commenced on May 26th, 1923, but from the start difficulty was experienced in securing sufficient steam, as the boilers had to be fired entirely with wood, and only greenwood was available.

The surface formation at both wells was a shifting sand, which caused much difficulty and necessitated the mixing of mud separately instead of following the usual practice of using debris from the hole for the purpose of making mud. This soft surface formation had to be shut off with 15½-inch casing, and in one case the only method of lowering the casing was by means of using a tree trunk in the derrick as a form of pile driver (Fig. 5).

After penetrating the loose surface strata harder formations were encountered consisting principally of limestone with strong water supplies which caused further difficulties in drilling and damaged the 15½-inch casing in the first well.

All the drilling was done with fishtail bits and these rapidly wore out in drilling the hard strata which had to be penetrated. Drilling was particularly difficult owing to the rapid alternation of hard strata and shifting sands, though well No. 1 was carried to a depth of 3,300 ft. and well No. 2 set 10-inch casing at 2,500 ft.

Well No. 1 was temporarily stopped at 3,340 ft. owing to a break at the top of the derrick. As a good gas show was struck just before the breakdown, it was decided to return and deepen the well. It was hoped to get down to 4,500 ft., but the bit jammed in the hole at 4,005 ft. and work was abandoned.

The inclusive cost up to the end of the first tour was appoximately £70,000. The second tour cost an additional £8,000, making a total cost of approximately £78,000. The actual cost of the machinery f.o.b. New York amounted to approximately £35,000.

I am informed that in addition to the boring mentioned above three bores were put down in 1910-1913 : oil and gas was reported from all. These were as follows :—

(*a*) On Coast (Bokakere). Depth 2,191 ft.
(*b*) One and a half miles inland (N. W. of Bonyere). Depth 1,114 ft.
(*c*) Four and a quarter miles inland (near Adul, Tano River). Depth 2,753 ft.

Boring at Tarkwa.

Diamond drilling was started at Tarkwa in the latter part of 1900. Over 70 boreholes were put down, all, with the exception of two, being directed towards cutting the eastern outcropping line of banket. The exceptions were at Kotraverchy and Taka Nasu to the south of the Prestea Railway. This line of banket has been repeated by folding and is situated some six miles west of Tarkwa. The Kotraverchy bore was inclined to the north-west at an angle of 54°, and attained a depth of 1,079 ft., bands of banket being intersected at from 921 ft. to 1,066 ft.

The object of all the bores was to discover the position and width of the auriferous conglomerate (banket) at depths considerably greater than those at which it was being worked in the mines.

Some of the bores were sunk vertically and some inclined at an angle approximately at right-angles to the dip of the "reef" and in this respect did valuable work, but the classification of the rocks passed through, and the value of the banket when assayed, must be taken very cautiously.

Even if there was no intention to deceive—and it must be remembered that £1 shares in mining companies on this field rose to as high as £40 as the result of core assays—the nature of the banket lends itself to irregularity. Should the drill pierce a large proportion of the non-auriferous quartz-pebbles of the conglomerate the assay will be very much less than would be the case were the auriferous hæmatite to preponderate. Mr. T. J. Foster, Secretary of the Tarkwa and Abosso Company, gives an amusing example of the anxiety of one local resident to put the best face value on his mining property. This was known as the "Comic Borehole" and the intersection and assay of the banket core was sent in somewhat as follows:—

Width.	Value.
17 inches	10 dwts.
23 inches	2 dwts.
5 inches	15 dwts.
12 inches	6 dwts.
Total 57 inches	33 dwts.

Actual developments at the points where drill-holes cut the reef have given results both ways. At Abosso a core that was poor was found to be in good average reef. A good one at Taquah was in reef of better average.

The richest borehole was probably Taquah C. 4 put down vertically with a Sullivan "C" Drill in 1904. It cut the reef at 317 ft., 17 inches of which assayed 75 dwts. 8 grs. of gold per ton. Development proved similar values over a greater width. The Taquah shaft was projected on this hole.

The deepest bore on the field is Fanti No. 6. This was sunk vertically in 1905. Banket was cut at 2,483 ft. and the core assayed 24 dwts. over 25 inches. A certain amount of deflection of the boreholes is believed to occur, but only a few have actually been surveyed to ascertain the amount. At Adjah Bippo mine holes "A" and "I," the former to 700 ft. and the latter to 980 ft., were put down at an angle of 53° from the horizontal and the corrected angle at the point where the banket was intersected was ascertained to be 62° or 63°. The deflection in both cases was down the dip of the beds, i.e., away from the outcrop (Fig. 6). On the Rand mines it is believed that the deflection was found to be in the opposite direction.

The initial drilling on this field was all done by American drillers using Sullivan "A," "B" and "C" types of drill. Later Mr. Edward Bray took on contract drilling. For deep holes the price was £1 per foot, the driller providing the carbon and the mining company the machine and power. Borts were tried for drilling but were found useless, and best quality carbons were found to be the cheapest in the end.

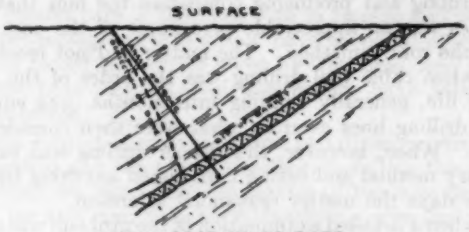


PLATE VI

Fig. 6.

The underground drilling in the mines was done by Sullivan "Badger" and type "E" drills, which have now been replaced by the "Baby Turbinar" A "Badger" type drill operating in the hanging-wall of the banket from 517. S., No. 10 level of Adjah Bippo mine is said by Sullivan to have established a world's record. This work was entirely in charge of an African "boy" named Ben, trained by the Taquah and Abosso Mining Company. The record of work may prove of interest.

Work commenced on January 16th, 1926, and was suspended on June 22nd at a distance of 603 ft. The banket reef was cut at 540 ft.

Time occupied was 156 days, but on 39 days no drilling was done, leaving 117 days equal to 5.16 ft. per day. The maximum done on any one day was 10 ft., attained on five occasions. The drill was run on compressed air, the pressure was low, probably averaging not more than about 50 lbs. Except when going through the banket, and 22 ft. of igneous rock, the hole throughout was in hard quartzite. . . .

The entire cost of this work was £829 10s., or 27s. 5d. per foot, but as the gross cost of the carbons, tools, and the sum of £11 5s. 8d. for assaying the core was charged against the job the actual cost probably did not reach 20s. per foot.

Wire Lines.

By B. J. Ellis (Member).

The general subject of wire lines has come very much to the fore within the last year or so, due to detail costing having brought home to drilling and producing companies the fact that the cost of wire lines was an appreciable percentage of the cost of a well drilled by the rotary method. The matter had not received much attention when cable tool drilling was the order of the day, as a fairly long life, generally running into months, was common for cable tool drilling lines even on what were then considered to be deep holes. When, however, this deeper drilling was turned over to the rotary method and casing lines lasted anything from five to twenty-one days the matter demanded attention.

At first when a detailed examination of the problem was attempted the information needed was hard to obtain. This was largely due to the fact that oil producing companies had no reliable records on which rope manufacturers could work, and further that wire rope manufacture was largely under rule of thumb methods, so that each manufacturer's experience was his most valuable stock in trade, which he did not wish to make public. When, however, it was seen that the user was definitely determined to help himself and, by the examination of samples, to try to find out for himself what features made a good rope, the manufacturer became immediately interested, and as a result of the co-operation between both user and manufacturer large strides towards better wire ropes, and more reasoned use of them, have been and are now being made.

It is practically impossible with cable tool drilling to find any way of comparing the service given by one line with that given by another on account of the difficulty of finding any standard for comparison. The actual life in weeks or months was the criterion, and working simply on this, and by trial and error, cable tool lines were brought to a standard which appeared to satisfy both user and manufacturer. Casing lines on cable tool wells were subjected to very little wear and had a very long life, so that little or no interest was taken in them provided they did not break down on the job.

Rotary drilling, however, demanded a casing line which would stand up to continual hard usage, and in view of the incidence of fishing jobs, the difference in depth of wells, loads and speeds, the time basis was found useless for comparison. Instead a successful attempt was made to base the service on the number of

ton miles of work done in lifting the drill-pipe, casing, etc., and, when due allowance was made for the equipment and for fishing and other heavy work, this was found to afford a very useful method of comparison.

The results obtained not only showed the way, which manufacturers were not slow to tread, towards better construction, but indicated very clearly that much better service could be had by improving the equipment on which the wire lines were used, and by taking greater care of the lines both in storage and on the well. Many oil producing companies now have a special department to care for and record the service given by wire lines, and where such departments have been started the results have fully justified the costs involved.

The whole subject divides itself into two divisions, viz., the wire lines themselves and the use of the lines, including the equipment on which they are run. The limitations of the wire line make it impossible for any manufacturer to produce a wire line which will give a reasonable life when run, fully loaded, at speeds up to 3000 ft. per minute on a 13 in. diameter rotary drawworks drum and round 22 in. diameter pulleys. The first step towards better service has therefore to be taken by user himself, and the trend of the improvements can be seen in the latest types of rotary equipment which he is now demanding. It is not possible to reduce the speed at which the rope is run; in fact an increase, if anything, is desirable, but it has been possible to increase the size of the rotary drawworks drum to 20 in. or even 25 in. and to increase the size of rope pulleys to 36 in. and in some cases to 48 in. Steps have also been taken to provide pulleys with grooves which accurately fit the line being used and to make these of some metal which will not quickly wear. These changes have resulted in an increase in the ton mileage of a given type of line by as much as 40 per cent. and the cost of making the modifications to the running gear is therefore well worth while.

Next, the user is able to help himself by careful cleaning and lubrication of the lines. It is not convenient to do very much in this direction when the line is actually in use on the rig, but the line can be removed periodically and put through a cleaning and lubricating machine. To be of any value the process must be very thorough, and a series of mechanically driven wire brushes, which thoroughly scour every part of the line as it is drawn past them, are necessary.

As regards the actual design of wire lines it should be realised that, though strength is an important factor, a much more important one is the ability to stand up to the high speeds and frequent

bendings round small pulleys. It has been found of advantage in this respect to make both the rope and the strand with a very much shorter lay than is customary with wire lines for other services. A certain amount of strength is sacrificed, but this can be compensated, as far as actual use is concerned, by the employment of a higher tensile wire. The decrease in strength should, however, be allowed for, and manufacturers should not be called upon to make their ropes test to the usual loads.

The number, size and arrangement of the wires and the size and type of core are still matters for individual preference among manufacturers and users, as experience to date has not shown that any one form of construction is definitely superior to any other. It has been proved that jute is quite useless as core material and that only the best manila, hemp or sisal, most carefully lubricated, will stand up to the work. Special flattened strand ropes have given good service, but the tendency seems to be to revert to the more ordinary round strand types of construction with several sizes of wires and with, in some cases, filler wires. The actual sizes of the wires and the strands and the way in which they should touch or clear one another to give the best results is a matter that is now under close investigation, and in this connection it should be remembered that the cross section of the wire in a plane at right angles to the rope varies with the lay and that all clearances, etc., are therefore liable to variation as the lay lengthens when the rope is in use. The design in this respect is largely a matter of compromise and experience, but such progress has been made in this direction in recent years by British manufacturers that the ropes now being produced are found to be the equal of any produced elsewhere in the world, while generally speaking their cost is low, due to the fact that the highest grades of wire, used in their construction, are manufactured in the country and do not have to be imported. Many of the best-known brands of oil well ropes manufactured in other countries are made of British wire, and as the wire, be it 80 or 120 tons per square inch tensile strength, so the rope.

Electrification of Oil Fields.

By W. S. Toplis, M.I.E.E., M.I.Min.E.

Electricity is now recognised as the most reliable, flexible and efficient form of power distribution medium. The general principles of adaptation for oilfield work have been dealt with on various occasions, notably at this Congress in 1925 by A. Nuchuta, and in papers read before the Institution of Petroleum Technologists in May, 1918, and February, 1924, by J. W. Burford [1] and C. H. McCarthy Jones [2] respectively.

The problem, therefore, resolves itself into (*a*) selecting the most suitable equipment for the fields; (*b*) evolution of design in order to overcome troublesome details of application. With this object in view the author endeavours to set forth briefly a few of the salient points regarding generation, distribution and application of electric power for oilfields.

Power Supply.

Generation.—Assuming that the supply has to be undertaken by the oil company the fuel question is of prime importance. Fundamentally it would be wrong to consume a portion of the principal product. Collieries now make every effort to arrange for, and provide suitable plant for utilising their more or less waste products for fuel purposes, consequently oil companies should work on the same lines.

On a par with the colliery's coal dust, refuse from screening plants, etc., and unsaleable combustible products, etc., the oil company has its residue casing-head gas. Dependent upon the oil-gas ratio, gasoline extraction, utilisation for repressuring, gas lifts, etc., there is usually a fair amount of surplus gas available. This gas, in spite of gasoline extraction, has a very high calorific value; for example, the gas from the Burma Oil Fields has the following properties :—

Calorific value B.Th.U.	Sp. gravity.	Average air content.
1050/1100. British, N.T.P.	0·8	6·0%

The air content is of course under the control of the field's staff and depends upon the condition of well heads, etc.

The combustion of this rich gas has to receive very careful attention, particularly so in respect to the design of burners and combustion chambers. It is essential to obtain a high degree of

[1] *J. Inst. Petr. Techn.*, 1918, **4** (16), 229–262.
[2] *J. Inst. Petr. Techn.*, 1924, **10** (42), 115–148.

mixture of the gas and air, otherwise unconsumed gas may flow through the flues.

The Schaefer Burner fulfils the above condition very efficiently. The general arrangement of this burner is shown in Fig. 1. It will be noted that the primary air is fed into the inside of the flame and the secondary air is obtained within the combustion chamber itself. This secondary air is preheated as it passes along the air passages in the combustion chamber walls to the outlet ports

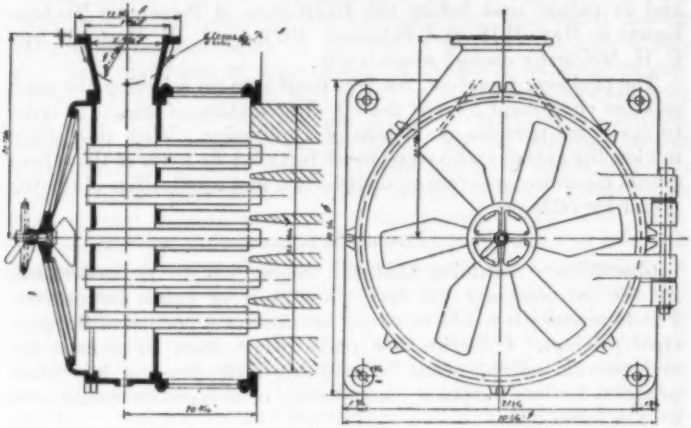


FIG. 1.

SCHAEFER GAS BURNER.

at the back end of the chamber. With respect to the actual burning of the gas (fireman's duties) much information of a theoretical nature can be obtained by a careful study of Mr. T. M. Hunter's paper, "Gas Firing Boilers."[3] With regard to the combustion-chamber itself, the cubic space of the chamber in boilers designed for coal or oil firing is usually too small for burning natural gas efficiently. This detail of design has had considerable forethought in some of the recent power stations burning natural gas in the U.S.A., and a reference to the details of design which has been published in the technical press of the U.S.A. are interesting and of value to the oilfields staff.

It is advisable for the boiler house staff to carry out a series of experiments in order to arrive at the maximum efficiency of working conditions of their plant. An important detail is to ascertain the

[3] The British Institution of Electrical Engineers, vol. 56, No. 270, January, 1918.

most efficient velocity of incoming gas with respect to combustion and rate of temperature fall through the boiler flue passages. It will be realised very quickly that if due care is not taken most of the evaporation will take place in the first row of tubes, and the flue gas temperature falls so quickly that the superheater is almost out of action.

In the author's experience a gas pressure between 11 and 14 ounces at the burner manifold and using Schaefer or Hunter burners and natural draught has given good results.

For boiler units of 30,000 lbs. evaporation and over, induced draught and a preheated primary air manifold should receive consideration. With this arrangement it is possible to adjust the combustion with great accuracy and maintain a minimum of excess air; in other words, conform with the conditions dictated by the chemical analysis of the gas. The approximate volume of air required for combustion of natural gas of say 1050 B.Th.U.

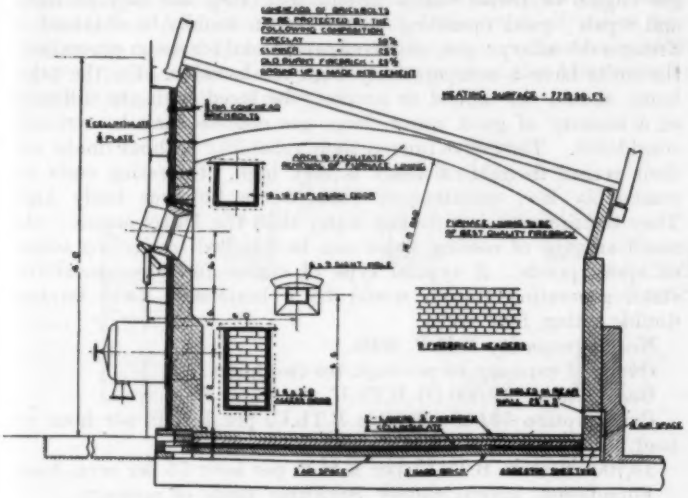


FIG. 2.

COMBUSTION CHAMBER FOR WATER TUBE BOILER.

per cubic foot is 10 cubic feet of air per cubic foot of gas. In practice this would be about 13 per cent. CO_2, as indicated by the Orsat apparatus. With careful adjustment 5 per cent. excess air should be sufficient for practical working conditions, or say 12 per cent. CO_2 by the Orsat.

Fig. 2 illustrates a combustion chamber which has given good results.

It is approximately 17 ft. 6 in. wide and 15 ft. deep and is dual fitted—that is, oil fuel burners as standby. There are six Schaefer burners, the secondary air ducts are clearly shown also the air-ports in the rear wall; these masonry air ducts are at a high temperature due to their proximity to the floor of the combustion chamber, thus the secondary air is preheated to a high temperature.

The explosion door shown is only 18 in. by 18 in., but it must be understood that there are a number of these doors on each side of the boiler walls. The method of conducting the flue gases to the chimney should receive very careful attention, otherwise serious explosions will occur when starting up adjacent boilers which are connected to the same flue.

Generators.—On many fields steam turbine generators would be selected without question. The initial cost is lower than either the gas engine or Diesel engine generators; they are easy to instal and repair; good operating engineers can usually be obtained at a reasonable salary; gas, oil or coal can be used for steam generation; the units have a comparatively high resale value. On the other hand, should the oilfield or property be faced with the difficulty of a scarcity of good water, large gas engines may be seriously considered. They have proved their reliability without doubt and their overall thermal efficiency is very high. Operating costs are reasonably low, maintenance charges are however fairly high. They require even less cooling water than the Diesel engine; this small amount of cooling water can be handled by cooling towers or spray ponds. A typical type of engine for a comparatively small generating station would be a horizontal twin tandem, double acting, four cycle.

Normal capacity B.H.P. 3000.

Overload capacity 10 per cent. for two hours.

Gas, natural, 10,000 (?) B.Th.U. per cubic foot.

Consumption 10,000 effective B.Th.U. per B.H.P. per hour full load.

10,700 effective B.Th.U. per B.H.P. per hour 75 per cent. load.

Foundation, approximately 700 cubic yards of masonry.

Weight, of engine *only*, approximately 940,000 lbs.

Diesel Engines.—The modern Diesel engine has high termal efficiency, but this gain is most probably offset by the fact that these engines require more experienced operating engineers and have high maintenance expenditure.

A comparision of Diesel engine generator plants with steam turbine generator plants shows that the former are more expensive, in fact, even more expensive than gas engine generators.

Distribution.—The selection of suitable transmission equipment requires considerable thought. Continuity of supply is of vital importance in oilfield work, and this can only be realised by proper installation and the selection of suitable protective gear.

The question of insulators is very important, and in deciding upon mechanical and electrical design, local conditions such as relative humidity, dust or salt in the atmosphere, maximum and minimum temperature during the year, altitude, character and extent of atmospheric disturbances, and last, but not least, the vermin pest, such as lizards, ants, etc. The larger birds, crows and vultures, etc., are also a great cause of interruptions. For the E.H.T. distribution the ring circuit split conductor system appears to fulfil all requirements. The author has had some eight years' experience of over one hundred miles of circuit laid out on this principle. Discrimination and isolation of sections of the line during the periods of "faults" have been very satisfactory. Admittedly it is a very expensive system, but this capital expenditure, *vis-à-vis* lost production due to total interruption of power, proclaims the advisability of adopting this system. An arrangement of E.H.T. distribution at 13,500 V. typical of the Yenangyaung Field, Burma, is shown in Fig. 3.

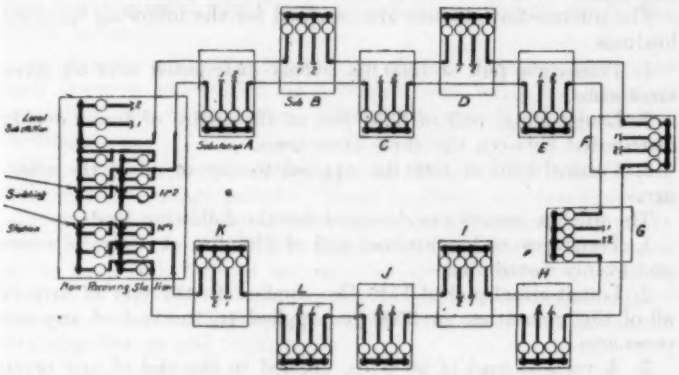


FIG. 3.

YENANGYAUNG. DISTRIBUTION.

The two split phase transmission lines which carry the power supply from the generating station to the main receiving station on the fields each consist of six No. 1/0 B. & S. stranded conductors carried on pin insulators supported on galvanised steel towers. These two lines run to the fields by different routes about half a

mile apart, so that damage by storm, tempest, etc., or other cause should not occur on both lines at the same time.

The towers are of Milliken manufacture built up of galvanised steel angles, the construction of the tower line being in accordance with the semi-flexible system. With this system two kinds of tower structures are used, these being classed as anchor or strain towers and intermediate towers.

The former class of tower is designed for heavy strains both longitudinally and transversely, while the intermediate towers are arranged to resist the same tranvserse strain as the anchor towers but have much less strength in a direction parallel to the line. The intermediate towers are also designed to allow for a certain amount of deflection due to unbalanced conductor pull without any permanent set. Put into other words, the principle amounts to a line that is anchored solidly at long intervals with plenty of slack in between, and provided with props to keep it in the air, the props being braced to resist transverse strains and being held in place longitudinally by the ground wire and the conductors themselves. This system of construction is used for all the E.H.T. transmission lines, including the ring mains, although due to the short runs, the proportion of intermediate towers used on the ring main is much less than on the transmission lines.

The intermediate towers are designed for the following specified loadings :—

1. Transverse pull of 1500 lbs. evenly distributed over all three cross-arms.

2. Longitudinal pull of 3750 lbs. at the centre of tower evenly distributed between the three cross-arms.

3. Vertical load of 1500 lbs. applied to any or all of the cross-arms.

The anchor towers are designed for the following loads :—

1. Transverse or longitudinal pull of 2100 lbs. at centre of tower and evenly distributed.

2. Longitudinal pull of 1710 lbs. applied to the end of any or all of the cross-arms, or 3500 lbs. applied to the end of any one cross-arm.

3. A vertical load of 2000 lbs. applied to the end of any or all cross-arms.

The intermediate towers for the transmission lines and the ring main are of similar design, the only difference being in length of the cross-arms, which in the case of the ring main towers have to carry two insulators. These intermediate towers are 50 ft. high overall, 6 ft. of this length being buried in the ground. The conductors are spaced 5 ft. apart in a vertical direction, the height of the lowest cross-arm from the ground being 30 ft.

On the ring main intermediate towers (type K) the split conductors are separated by a horizontal distance of 3 ft. On the transmission lines intermediate towers (type J) the two split conductors are carried on either side of the tower and the horizontal distance between them is 6 ft.

The anchor towers are of four types, type E and F being used for the transmission lines and types G and H for the ring mains. The type E tower is 62 ft. high overall with a horizontal spacing of 12 ft. between conductors. Type F tower is 44 ft. high overall with the conductors spaced at 6 ft. centres. Both the types G and H towers are 44 ft. high overall, arranged with four conductors on each cross-arm. The only difference between these two types is that the outermost conductors are spaced 12 ft. apart in the type G tower and 14 ft. apart in the type H tower.

As previously mentioned, these towers are built up of angle steel of different sections, ½-inch bolts being used throughout. All the material of which the towers are constructed is heavily galvanised. Clamps are provided at the top of the tower to carry a galvanised steel protecting and earth wire. As a general rule the towers were not set in concrete. Concrete was only used where the foundations were not good or where there was a possibility that heavy rainfall might have a tendency to disturb the footing of the tower.

To comply with the regulations of the Indian Government each tower is surrounded by a barbed wire fence and bears an enamelled iron danger sign printed in several of the native languages.

The standard line insulators used on all the E.H.T. lines are of Thomas high voltage pattern. These insulators are provided with all metal galvanised pins and the line cables are secured to them by means of "Memco" insulator clamps. On the anchor towers and at the dead ends both at the sub-stations and the power station, suspension type insulators are used, two 6-inch discs being furnished for each conductor, these tension strings being fitted with galvanised straining clamps and fittings.

The transmission line conductors are No. 1/0 B. & S. 7 wires hard drawn copper strand.

The ring main conductors are of No. 3 B. & S. These are solid conductors. The protecting and earth wire is a ⅜-inch diameter galvanised mild steel stranded cable having a breaking strain of 10,000 lbs.

The steel earth wire suspended above the electric conductors is essential. Its function is not only for earthing the towers, etc.,

and providing a direct earth circuit for the fault current, but as a protection for the electric wires from falling rigs caused by fire or tempest.

Regarding sub-stations, in the early days of oilfields electrification the design of sub-stations followed the general practice of the Electric Power Co.'s. This type under construction is illustrated in Fig. 4. It did not require long experience to demonstrate the unsuitability of this type; it was altogether too permanent and costly. The oilfields requirements are a design on the lines of a semi-portable sub-station in order that the S.S. may follow the fields activities in drilling and extensions generally. It must be realised that the various " centres of gravity " of the " electrical load " areas on the field are migratory, consequently the S.S. should be capable of being moved to the various centres. A type of S.S. which has proved very satisfactory is illustrated in Fig. 5. A summary of the foregoing features of design is briefly as follows :

Early Type.—Expensive masonry structure to protect the transformers and switchgear, also special steel structures on the roof for taking the incoming and outgoing E.H.T. lines, thus constituting a permanent structure very costly to move.

Modern Type.—Standard towers from stock for the incoming and outgoing E.H.T. lines.

Waterproof portable switch cubicles and transformers, thus enabling the whole S.S. to be disconnected, transported and re-erected in a minimum of time and expense.

Each of the types illustrated has a capacity of 1000 K.V.A. at 13·5 K.V. pressure.

This portable feature so essential for oilfields can be carried out very conveniently and at a minimum of expense by selecting for fields stock a series of switch cubicle units which can be built up to sub-station requirements in exactly the same manner as the unit book case system.

Low Tension Distribution Network.—This section of the oilfields electrification work usually presents a number of difficulties. In the first place the field is, in most cases, of very irregular and broken-up ground, thus rendering it most difficult to lay out the routes of the distributors. In the alignment of the distributors it is advisable to work in an interconnection with the corresponding distributor from the adjacent S.S., thus safeguarding against total interruption of power.

The difficulties are mostly of a mechanical nature—*e.g.*, safeguarding against damage to the conductors caused by rig fires, falling rigs, sand lines fouling the conductors and causing " short-circuits." In order to illustrate the importance of this point the

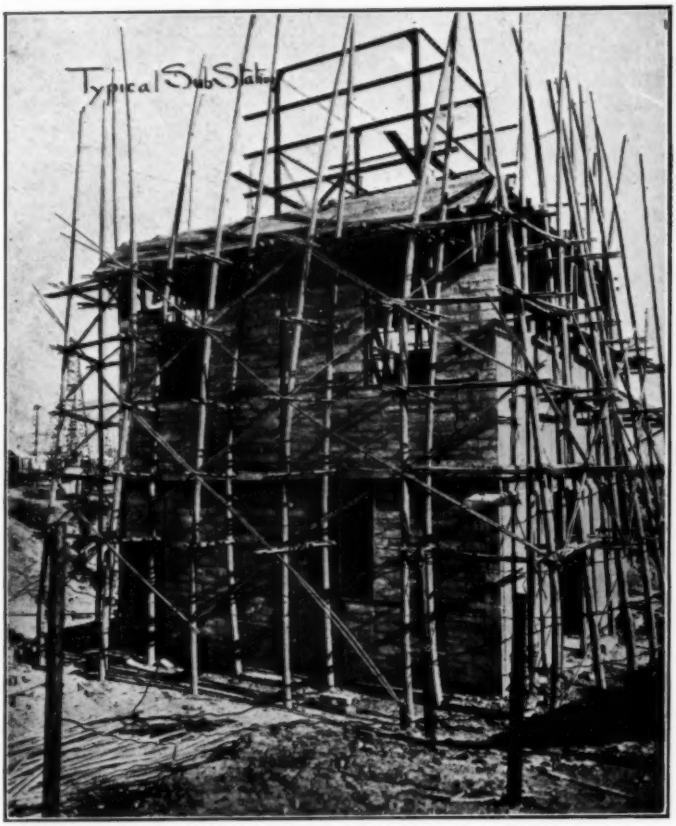


FIG. 4.

EARLY TYPE OF SUB-STATION.

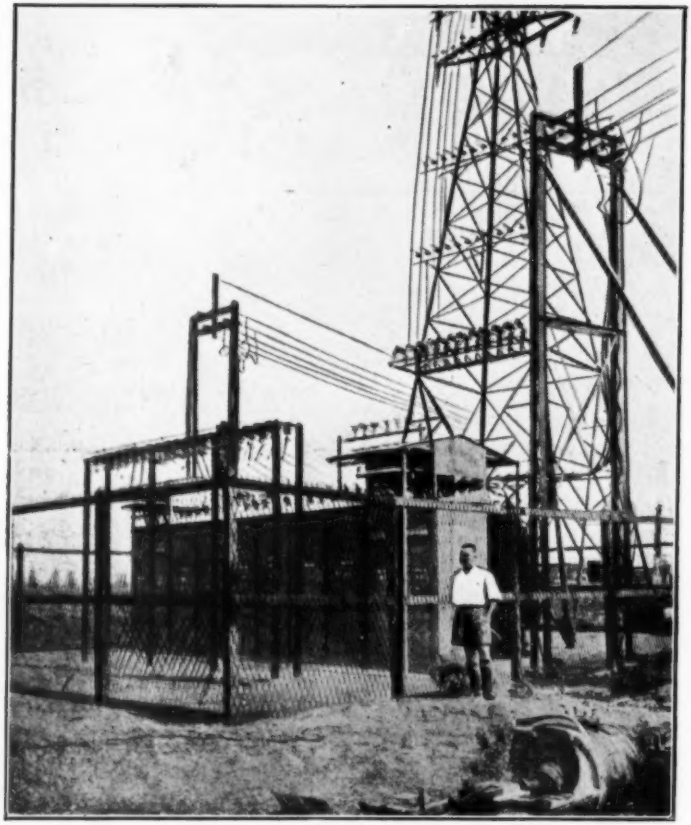


FIG. 5.
PORTABLE TYPE OF SUB-STATION.

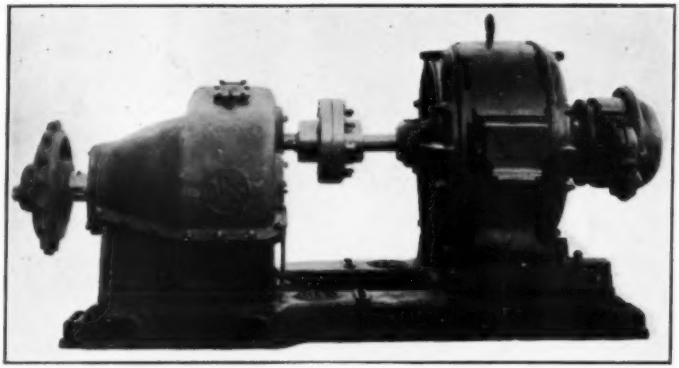


FIG. 6.
EARLY TYPE OF GEAR BOX.

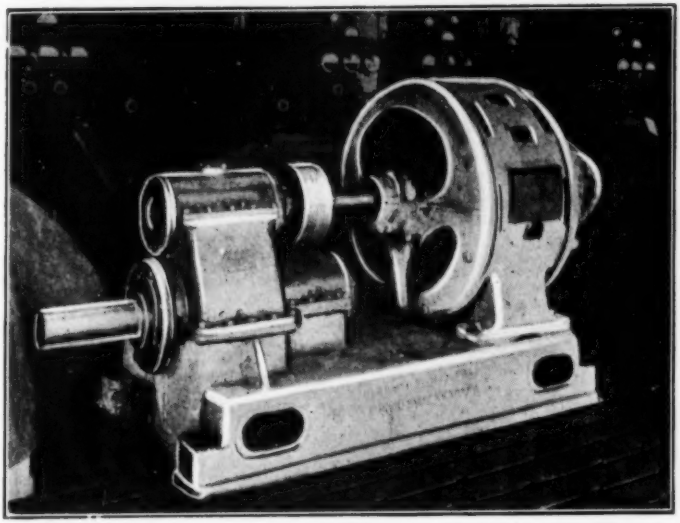


FIG. 7.
MODERN TYPE OF GEAR BOX.

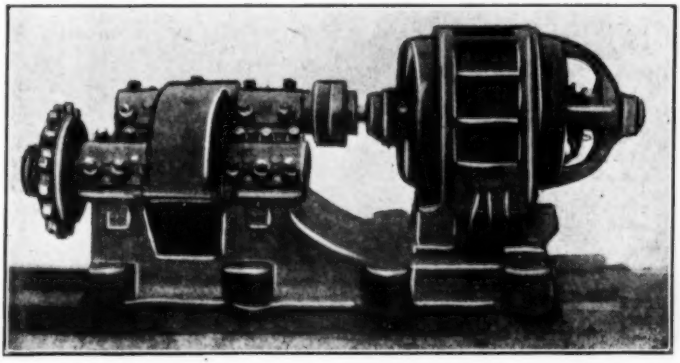


FIG. 8.
AMERICAN TYPE OF GEAR BOX.

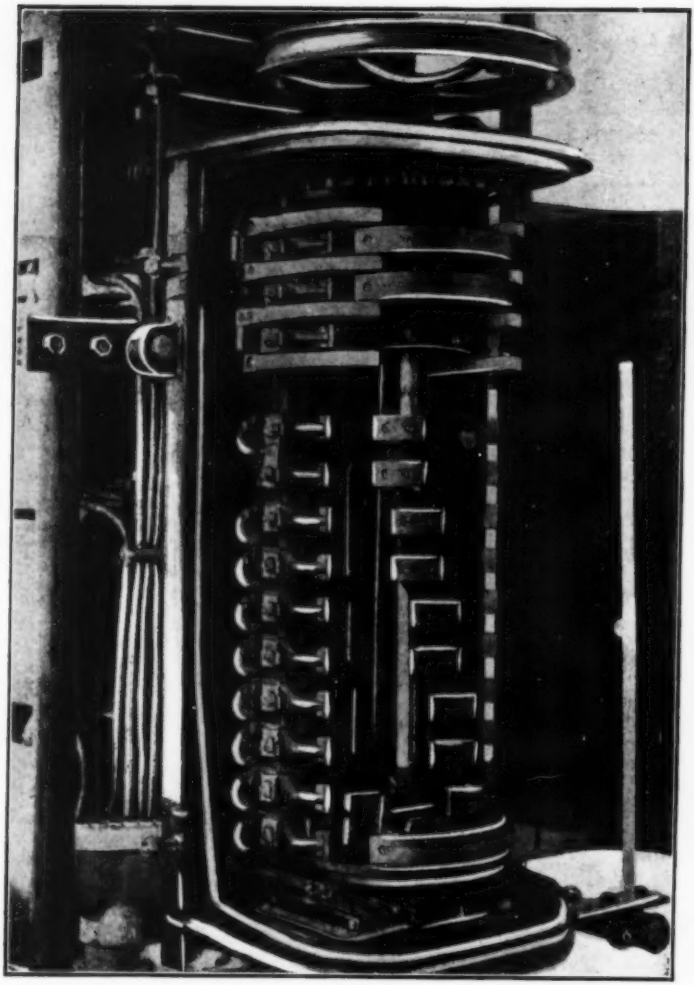


FIG. 10.

EARLY TYPE OF CONTROLLER.

following is an extract from the Burma Oil Field Distribution Dept.'s log book :—

Date.	Distributor affected.	Dept. responsible.	Cause.
2/1/27	I. 1	Prod. Dept.	Sand line fouled service wires at Well 888.
12/1/27	D. 1	Rig. Blg. Dept.	Rig fell across service wires at Well 142.
2/7/27	D. 1.	„ „	Wooden plank fell across service wires at Well 873.
6/8/27	D. 2 and 3	Prod. Dept.	Sand line fouled service wires at Well 1347.
10/8/27	M.R. 4	Rig. Blg. Dept.	Rig. guy wires at Well 58 fell across service wires.
2/9/27	G. 3	„ „	Wooden plank fell on distributor from Well 475.
15/9/27	A. 4	Prod. Dept.	Sand line fouled service wires at Well 471.
26/10/27	A. 4	„ „	Ditto.
30/11/27	K. 1	Rig. Blg. Dept.	Wooden plank fell across service wires at Well 1636.
3/12/27	L. 3	„ „	Guy wires at Well 882 fell across service wires.
17/2/28	L. 5	Prod. Dept.	Well head tank allowed to collide with the final pole at Well 301.
20/2/28	M.R. 3	Rig. Blg. Dept.	Guy wire at Well 887 fell across the service wires.
19/4/28	J. 1	Prod. Dept.	Sand line at Well 1694 fouled the service wires at Well 1904.
1/5/28	A. 4	„ „	Sand line fouled the service wires at Well 471.
19/5/28	I. 2	„ „	Sand line fouled the service wires at Well 687.
25/5/28	M.R. 4	„ „	Sand line fouled the service wires at Well 1860.

In addition to the mechanical difficulties the distribution engineer is faced with a very serious electrical difficulty that is the inherent low power factor of oil well pumping motors. The average P.F. of the electrical input to an area where two speed pumping motors are used is on the average about 48 per cent., consequently the voltage regulation of the distributors is bad, and the weight of copper per distributor becomes excessive ; however, there are several ways of solving the problem. In the case of the Burma fields the solution has been effected as follows :—

The distributor and service conductors are carried on Bates expanded steel truss poles.

Two sizes of poles are in use—30 ft. poles, 4 inches wide, being used for service lines and 35 ft. poles, 6 inches wide, for the distributor lines.

These poles are capable of withstanding horizontal pulls of 760 and 1320 lbs. respectively—applied 2 ft. from the top of the pole.

The distribution lines are all of the same size. They consist of two 4/0 B. & S. hard drawn copper stranded conductors connected in parallel per phase. The conductors, which are divided into two separate 3-phase circuits, are carried in triangular formation on 3-inch angle iron cross-arms. Insulators giving a very high factor of safety have been chosen; they are good for a working pressure of 6500 V., although the actual working pressure is only 440 V.

The insulators are fitted with bronze Memco clamps for the attachment of the conductor.

All the joints are made with Macintyre sleeves. Each pole is fitted with 3-inch angle iron bayonets carrying U bolts for the attachment of the "earthed" protecting steel wire.

The protecting wire is galvanised mild steel stranded cable $\frac{5}{16}$ inch diameter. H pole structures built up of 35 ft. poles braced together with channel irons are used for long spans and at "section switches."

There are some 16 sub-stations (1000 K.V.A. each) with an average of four distributors per S.S., and distributors of the same name or number from adjacent sub-stations are provided with interconnecting switch at their meeting points. This arrangement allows of a number of combinations of emergency supply in the event of a S.S. failure. These section switches are of the open-air type, under hung and mounted on petticoat insulators.

Services are taken off the distributors through non-automatic 3-pole open-air type hand operated oil switches. These switches are mounted on the distributor poles just under the cross-arms. As a general rule two or three wells are fed from one service and the actual service tap is made by a 4-bolt bronze clamp.

The service lines are three 1/0 B. & S. stranded copper conductor mounted on the same type of insulator as that used for the distributors; short cross-arms, one insulator per arm bolted to 30 ft. Bates' poles and the protecting or "earth" above the service lines.

The 3-phase service wires and the earth wire are all taken into the motor house and terminate at the metre board, which includes three single-pole ironclad cartridge fuses and a 3-phase watt metre. From the above brief description it will be noted that an extremely flexible distribution system has been laid down. Any distributor can be quickly isolated or the whole of portions of each S.S. load can be transferred to adjacent S.S. service lines, can be quickly "made dead" and isolated in the case of fire or similar trouble by simply opening the service oil switches, and any service can be permanently or temporarily disconnected by means of the bronze clamps. Distributor poles are provided at intervals and busy centres with large enamelled plates bearing the number of the

distributor, so that no confusion arises when the fire brigade or breakdown gangs request the immediate disconnection of a distributor or the electrical engineering staff are rearranging the loading or switching of distributors. In addition to these number plates each distributor control panel in the S.S. is provided with a special plate in which are marked the numbers of each service fed from the distributor and also the numbers of all the wells connected to each service. This arrangement is of extreme importance to the S.S. operator as it facilitates the orders he may receive from the electrical staff or the fire brigade.

With regard to "regulation" the sub-division of the distributor into two parallel circuits improves the electrical regulation, but the installation of static condensers at the far ends of all distributors has proved of the utmost value and importance.

The power factor (average) at the S.S. without condensers is approximately 50 per cent., but with the condensers connected it rises to 80–90 per cent.; thus all distributors have a reasonable regulation.

Each condenser is of 100 K.V.A. capacity, installed in one unit. In appearance these condensers are not unlike transformers; they are oil-immersed in large iron tanks, and mounted thereon is an automatic circuit breaker, ammeter and discharging resistance.

Application.

Rotary Drilling Equipment.—The application of electric motor drive to rotary drilling was first attempted in the early 1920's. Various schemes for connecting the motor to the draw works line shaft were tried out, but the ratio of motor speed to line shaft speed being so high all kinds of mechanical difficulties were met with. The first development was to introduce chain-driven countershafts, but the results were not satisfactory. The next improvement, which brings us down to present practice, was the development of reduction gears. In the early examples standard reduction gears were used, but the gear box and bed plates were not suitable for the rough work of the oilfields.

The chief features of general design which the manufacturer should embody are briefly :—

1. Ease of assembly and dis-assembly because of the transfer from well to well on the field.
2. Low centre of gravity.
3. Bed plate to be as massive as possible and void of flexure.
4. Adequate number of holding-down bolts in view of the great strains experienced in rotary drilling.

A close comparison of the following illustrations will demonstrate the foregoing.

Fig. 6 and Fig. 7 show the evolution in British design. The former did not comply with any one of the desirable features of design, whilst the latter proved itself adequate in all points.

Fig. 8 illustrates American design, which also fulfils the requirements, especially item 4. It will be noted that there are some 16 holding-down bolts.

Horse Power of Motor.—Originally 75 and 100 H.P. motors were tried out, but the tendency has been towards heavier and more powerful equipment to permit of drilling deeper wells in shorter time, and as a consequence the 75 H.P. equipment is becoming obsolete. Its practical application is limited to light-drilling in comparatively shallow fields. The 100 H.P. equipment, although still in use, is rapidly being replaced by 125 H.P. motors and twin 100 H.P. equipments. While these equipments are more expensive than the 100 H.P., the saving in upkeep and in days drilling, which means saving in labour, saving in interest on capital invested in the whole rig, etc., will more than pay for the additional cost in a comparatively short time.

Specifying the Horse Power of Motor for Rotary Drilling.—This is a very vexed question. The conflicting factors are capital cost of motor equipment and speed of " pulling out."

For efficient and economical drilling the " pull out " speed must be fast, but this entails high powered motors at high cost.

With a view to arriving at a basis for specifying suitable equipment some form of drilling performance must be specified upon which to build up recommendations. With this object in view an example may be worked out based on the following assumptions :—

One stand (fourble), 86 ft.
High speed " pull out " in 60 seconds.
Low speed " pull out " in 90 seconds.
Maximum drilling speed 90 to 120 r.p.m.

The above performance, satisfactory from the drilling point of view, may, however, entail a motor expensive in capital cost.

To illustrate the point the following approximations may be calculated and a rough idea of the size of equipment obtained :—

High speed " pull out " rate is 1·43 ft./sec.
Low speed " pull out " rate is 0·95 ft./sec.

Speed of winding rope on to drum with a block ratio of—

6 : 1 is for	H.S.	8·58 ft./sec.
	L.S.	5·7 ft./sec.

The drum barrel is approximately 12 inches diameter and takes 37 convolutions of 1 inch diameter rope.

In practice a certain amount of rope stock is wound on the drum, thus assume a working diameter of 15 inches at the commence-

ment of the wind and building up to say 20 inches, thus the length of rope per mean turn is 4·97 ft.

Revolutions of drum at the rate of 8·58 and 5·7 give 103 and 69 r.p.m. for high and low speed lift respectively.

Assume drilling at 2000 ft. with 6-inch pipe.

Weight of pipe, mud and tackle, 78,000 lbs.

With six lines the mechanical advantage of the "rig up" gives a rope pull of 16,000 lbs.

Power Required at Drum.—Radius of winding path at commencement 8 inches mounting up to 11 inches.

Static torque at start, 10,650 ft./lbs.

Static torque at start, 14,700 ft./lbs.

Maximum H.P. input at 103 r.p.m., 210.

Maximum H.P. input at 69 r.p.m., 193.

Note.—The first few stands are not pulled on the high speed, because time has to be allowed for the mud to flow out of pipe; thus the input of 210 H.P. will be required only for the latter part of the "pull out," that is when it is possible to go into high speed due to the reduced length of pipe.

The modern American practice of using 100/300 H.P. motors appears to confirm the above approximations.

The drum horse power must be increased to allow for the losses in drum works and gear box. Assume a mechanical efficiency of 90 per cent., thus motor H.P. is 235 and 215 respectively.

Drilling.—Assuming a table speed of 120 r.p.m. as being satisfactory, it is found by experiments that the electrical input required is 75 K.W. to 90 K.W., that is 90 to 100 H.P.

The following observations were made at a well on the Burma field :—

Mechanical Data.

Gear box sprocket	16 teeth.
Line shaft sprocket	20 „
Gear box r.p.m.	240 „
Line shaft r.p.m.	192 „
Drum H.S. r.p.m.	128 „
Drum L.S. r.p.m.	86 „
Table r.p.m.	93 „

Drum Conditions.

Rope, 1 inch diameter.
Block, 6 lines.

Drum Barrel.

1st lap 32 turns radius	8·0 inches.
2nd „ 37 „ „	9·0 „
3rd „ 37 „ „	10·0 „
4th „ 12 „ „	11·0 „
Total wind of rope	= 569 feet.
Total lift	= 95 feet approximate.
Average length of sand	86 feet.

Note.—The difference of 9 ft. is reasonable taking all things into account—*i.e.*, stretch, varying length of stands, etc., etc.

Drum speed .. .. 86 r.p.m.
128 ,,
Mean rope speed .. .. .. 405 feet per minute.
and 605 ,, ,,
Block ratio 6 : 1.
Rate of L.S. pull out is 67·7 ft. per minute.
Rate of H.S. pull out is 100·8 ft. per minute.
Calculated time of L.S. pull out 76·4 seconds.
Observed time 82 seconds.
Calculated time of H.S. pull out 51·2 seconds.
Observed time 51 seconds.

Time taken to pull out 26 stands complete 1 hr. 12 min.

OBSERVATIONS "PULLING OUT."

Lift No.	Number of stands.	Time seconds.	Position clutch.	K.W. Start.	K.W. Finish.	H.P. Start.	H.P. Finish.
1	—	—	Low	128	107	157	131
2	25	83·5	—	120	105	146	128
3	24	83·0	—	127	103	155	126
4	23	81·2	—	120	100	146	122
5	22	81·2	—	120	98	146	120
6	21	50·0	High	172	150	210	183
7	—	—	—	166	143	202	175
8	—	—	Low	—	—	—	—
9	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—
11	16	52	High	135	113	165	138
12	15	51	—	125	105	150	128
—	—	—	—	—	—	—	—
26	—	—	—	93	80	113	98

Remarks :—
Voltage 480–430.
Gear box speed 230–240 r.p.m.

Nos. 6 and 11 was an attempt to use the H.S. gear, but the automatic switch operated.

OBSERVATIONS.

Drilling.—From the above observations it is clear that a single 100 H.P. motor is insufficient for the mechanical conditions obtaining, especially so when an objective of 3000 ft. is taken into account.

In order to maintain the time and drilling schedules a twin equipment must be used—*i.e.*, 2–100 H.P. motors with hand control gears similar to the hand wheels for the Hild control gear.

It will, of course, be understood that the two motors do not work continuously ; for example, during drilling only one motor is switched on and the other runs idle, but when pulling out or doing similar hard work the idle motor is switched on to help. The watt-metre graphs show this feature very clearly.

Fig. 9 is a reproduction of the chart from a graphic recording wattmetre (one for each motor) showing the input to a twin 100 H.P. rotary drilling equipment. These daily charts furnish information of the utmost importance to the drilling department. For example, the approximate depth of the well is found by counting the number of "peaks" when coming out or going into the well and multiplying by the average length of a stand. Some idea of the formation is obtained by noting the power taken during drilling; time-keeping and a mass of evidence on the other matters is revealed to the careful scrutiniser.

Control Gear.—This section of electric equipment for oilfields is now receiving the attention it warrants. In the early stages of electrification of oilfields the simplest form of controller—that is, the finger and segment type—was installed (see Fig. 10). This type of controller is entirely unsuited for the arduous duty of drilling or even rod and tube pulling at producing wells. The arcing and burning at the points of make and break is so severe that the cost of renewals and time lost to the well during these reconditioning periods rendered it necessary to improve the design; the situation was serious. In the author's experience this type of controller required a complete set of new fingers and segments per month. It is unnecessary to go into the history of the development in design up to present-day practice, but one or two outstanding features may be recorded. Firstly, the immersing of the controller parts in oil did not prolong the life of the parts to the extent anticipated. Secondly, the controlling of the stator circuit was so arduous that it was inadvisable to attempt to combine this circuit in the controller operating the rotor circuit, a separate control panel electrically operated from the rotor controller proving more reliable and serviceable. The present-day equipments feature some form of mechanical contactor operated by a camshaft in a similar manner to the operation of the valves on a motor-car engine.

These contactors are virtually self-contained unit switches and one or more contactors, according to the capacity of the controller, are used per point or notch and for heavy work a magnetic blow out is fitted to each contactor.

Fig. 11 illustrates the general arrangement, and it is very illuminating to compare the details with those of Fig. 10 illustrating the early types of controllers. These contactor switches make and break the circuit with a quick motion, and it is impossible for the operator to have the controller in a position midway between notches, thus maintaining an arc between the contacts which ultimately destroys them by burning.

An important detail of design is the method adopted for opening the contactors. It is essential for them to be forcibly opened by the

cams, *not* by springs. Should the contactor contacts become stuck or welded together during a heavy period of work it is necessary to have considerable force to open them. If they remain closed, which is very probable when the opening force is a spring, disastrous "short circuits" will take place in the controller. Cam opening and closing is the best proposition, but cam opening and spring closing may be accepted as the next best arrangement. The contactors controlling the stator circuit should be interlocked in such a manner that it is impossible for the "forward" and "reverse" speed contactors to be closed simultaneously.

Another important feature is to arrange for the rope wheel to be mounted on the frame of the controller and not directly on the camshaft. By adopting this arrangement the friction of the rope does not affect the registration of the star wheel when making or breaking contact after the point halfway between notches has been passed.

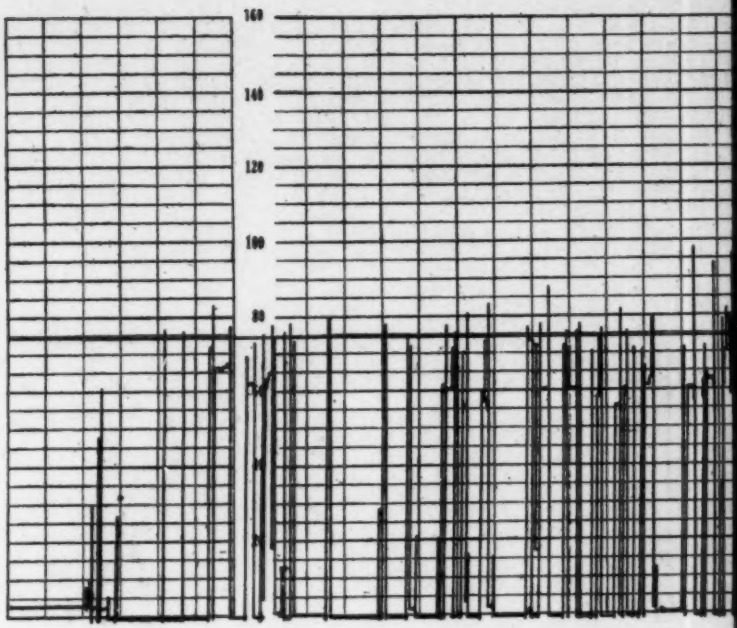
Fig. 12 illustrates a modern type of British control equipment for rotary drilling and Fig. 13 the American contemporary. In both cases a sub-dividing controller is shown in order to obtain fine adjustment of speed, but experience has shown that by careful grading of the resister this refinement may be discarded, thus reducing transport charges.

The nature of the duty and the increasing power of motors involved in modern rotary drilling will bring the control equipment into the class of the all magnetic contractors. This is the type of controller used for the most arduous duties,—*e.g.*, railway work, steel works and colliery equipment. On the Californian fields several of these control equipments have been tried out with great success.

Automatic feed is the outstanding development of modern rotary drilling. Drilling in all parts of the world with automatic feed reveals such advantages as straighter hole, faster drilling, lower power costs, longer life of drill-pipe, less strain placed upon equipment and operators, lower maintenance, and reduced risks and uncertainties incident to hand-feed drilling. Automatic operation is dependent upon the condition that the downward feed of the drill-pipe is a function of the power required to rotate the bit at the bottom.

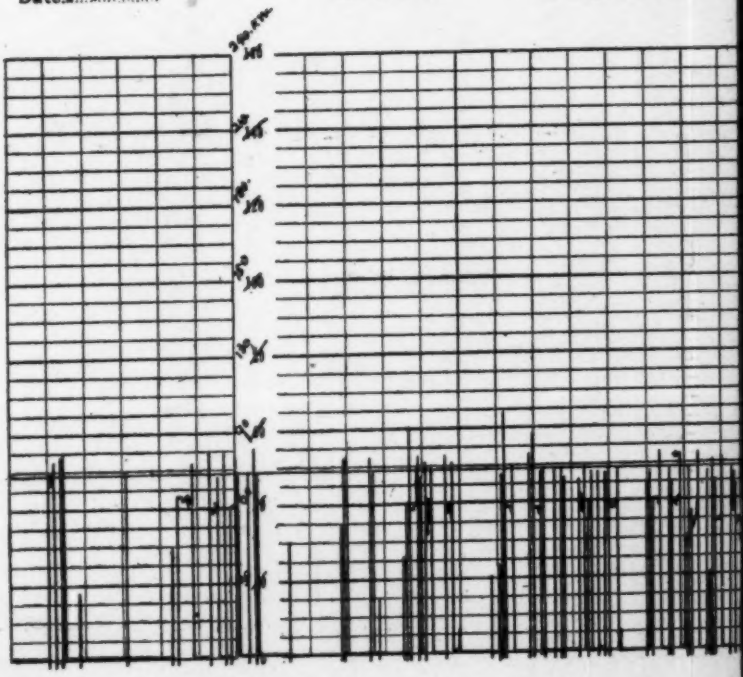
This relationship is adjustable, and in the Hild system depends upon the relative speeds of the two motors, which speeds may be varied independently. In the Halliburton system the automatic feature is obtained by changes in sprocket ratios. This automatic feed was developed concurrently by F. W. Hild, of Los Angeles, and E. P. Halliburton, of Duncan, Oklahoma, and each use the same principle of a special combination mechanical differential reduction gear. The Hild method, because of its two motors,

Date 3-8-38 Lot No. 48227 S-3 Westinghouse Recordi



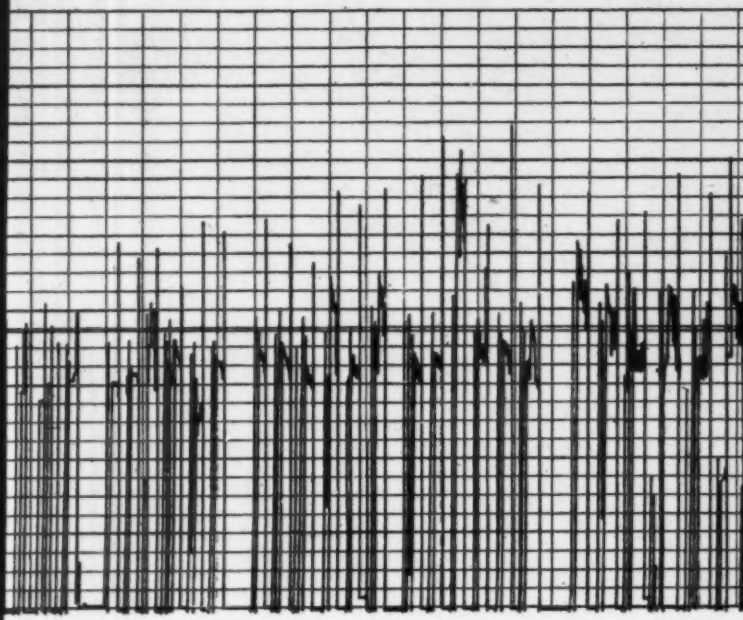
3PM 2PM

Date 3-8-38 Lot No. 48227 S-3 Westinghouse Recordi



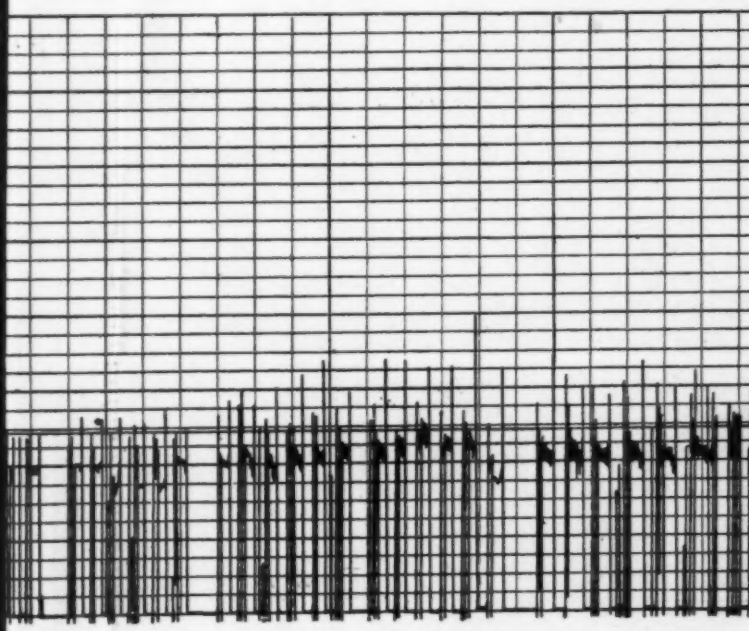
3PM 2PM

nghouse Recording Instrument. Circuit No. WELL 1880 NO. 2 MOTOR. Chart Style No. 84646



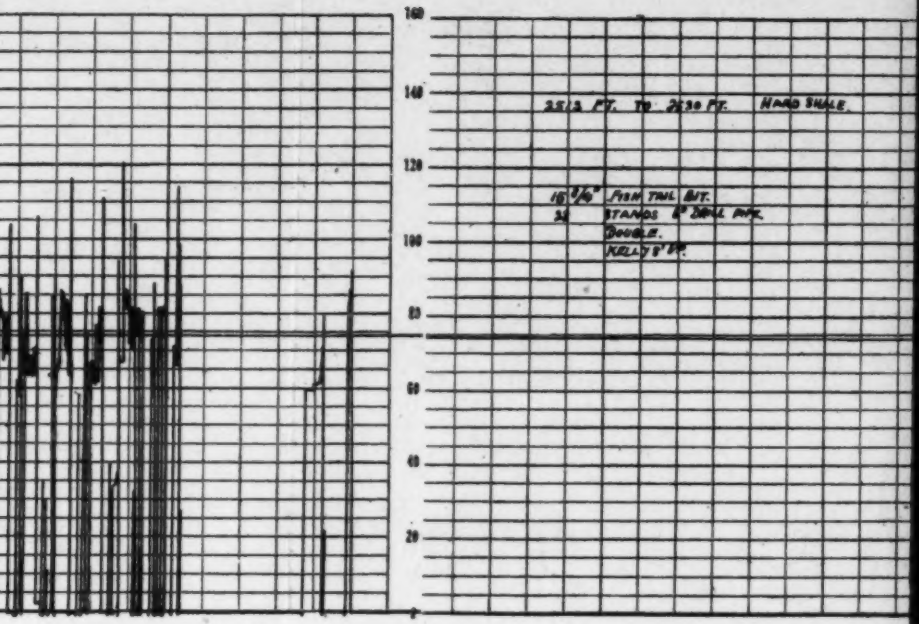
2 PM 1 PM

nghouse Recording Instrument. Circuit No. WELL 1880 NO. 1 MOTOR Chart Style No. 84646



2 PM 1 PM

Style No. 84646-C. Date 8-8-38 Lot No. 41227 B-3 Westinghouse Recording I



12-M 11 AM

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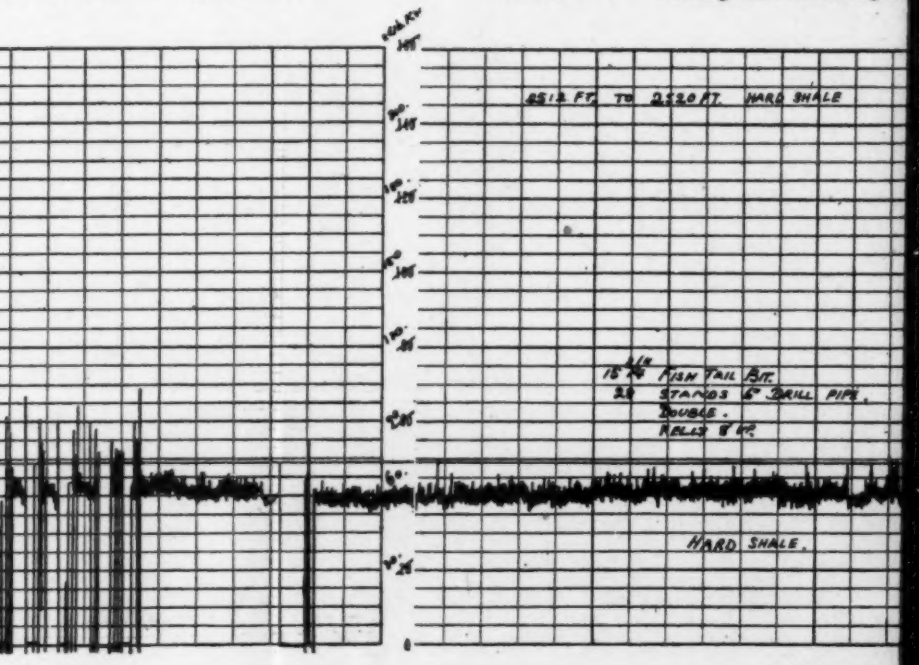


12-M 11 AM

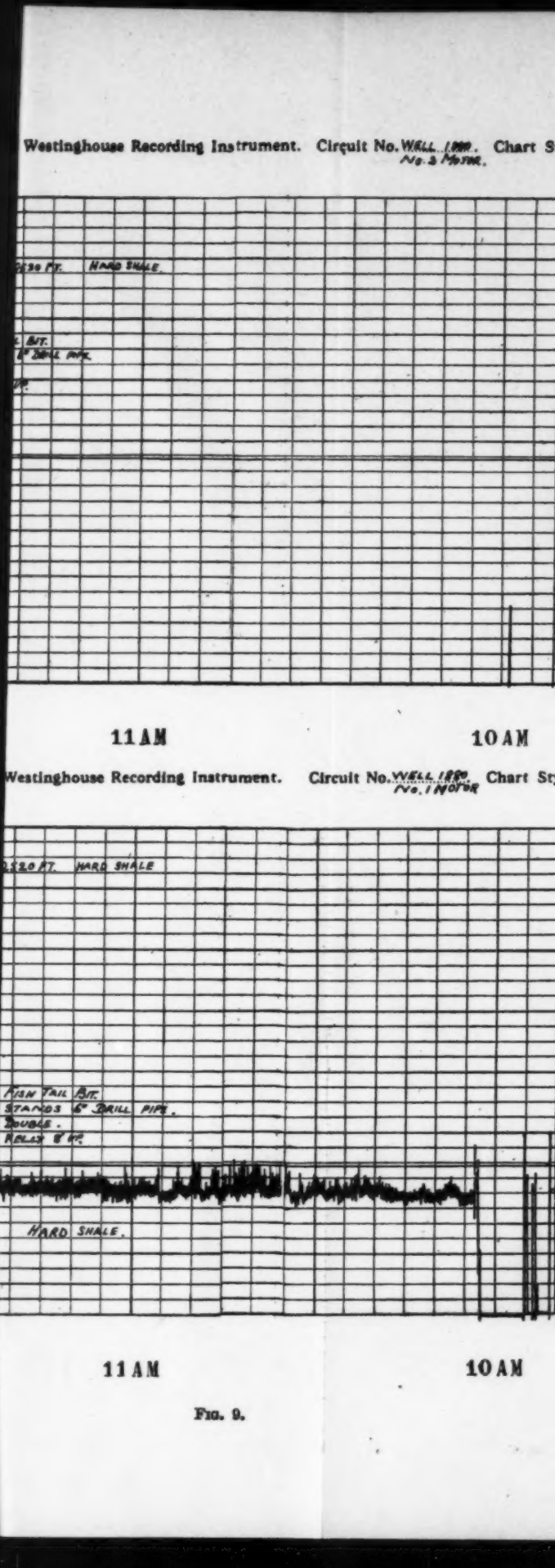
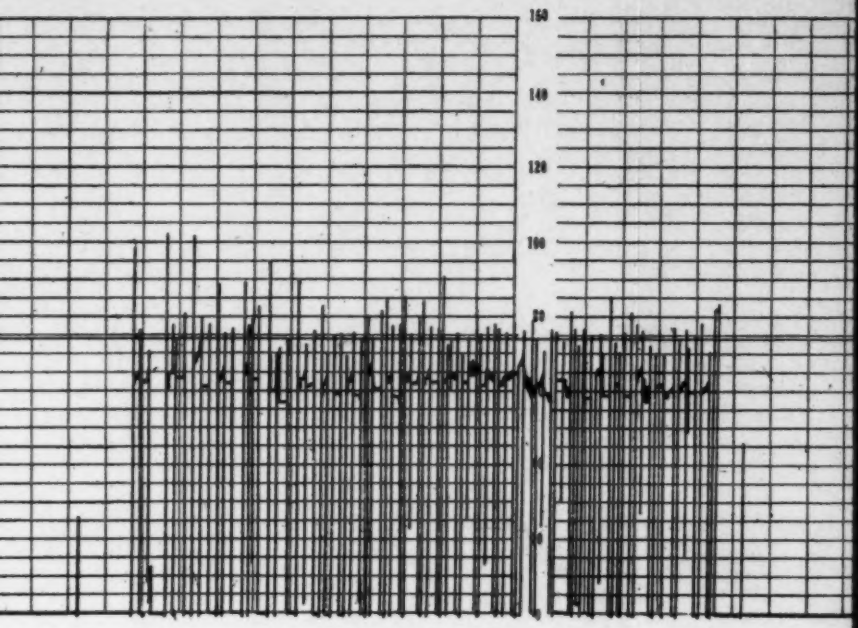

Westinghouse Recording Instrument. Circuit No. WELL 1880. No. 2 MOTOR. Chart S
HARD SHALE.
11 AM
10 AM
Westinghouse Recording Instrument. Circuit No. WELL 1880 No. 1 MOTOR Chart St
HARD SHALE
FISH TAIL BIT.
STANDS 6" DRILL PIPE.
DOUBLE.
REAM 8 FT.
HARD SHALE.
11 AM
10 AM

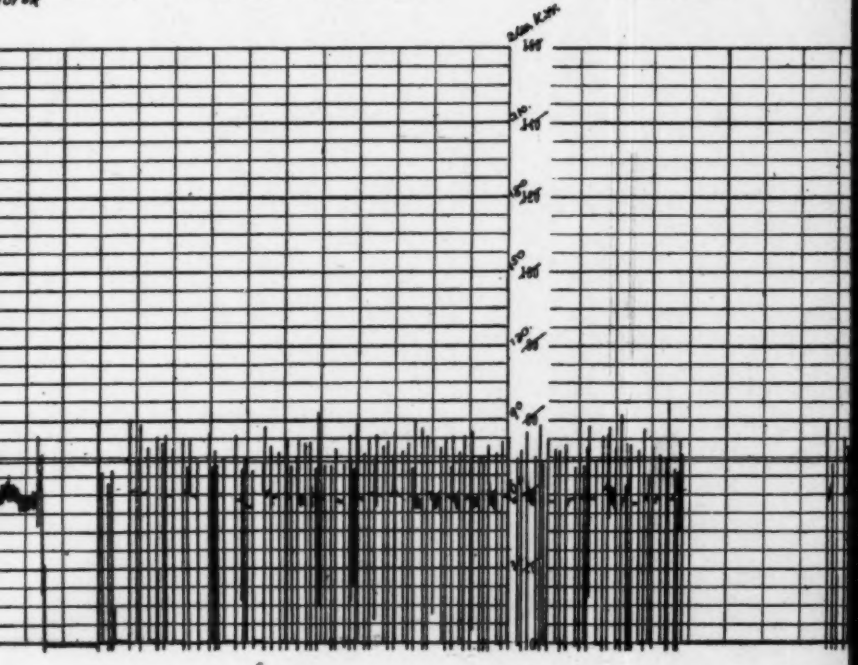
FIG. 9.

Chart Style No. 84646-C. Date 3-1-97... Lot No. 46227 S-3 West



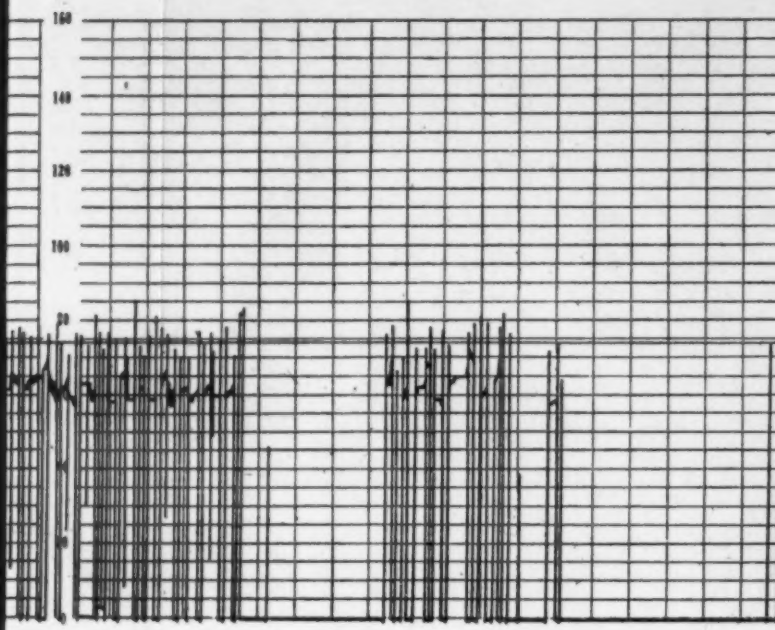
10 AM 9 AM

Chart Style No. 84646-C. Date 3-2-97... Lot No. 46227 S-3 West



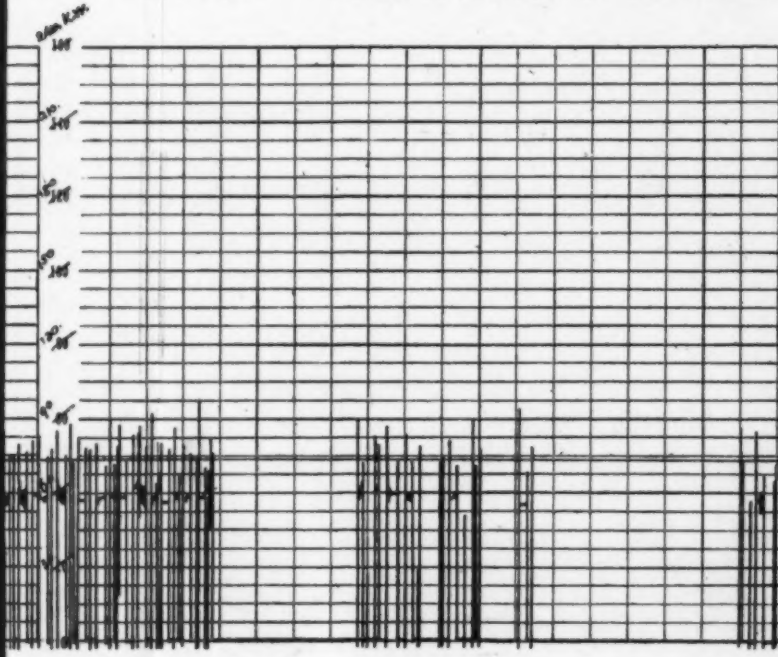
10 AM 9 AM

Lot No. 48227 S-5 Westinghouse Recording Instrument. Circuit N



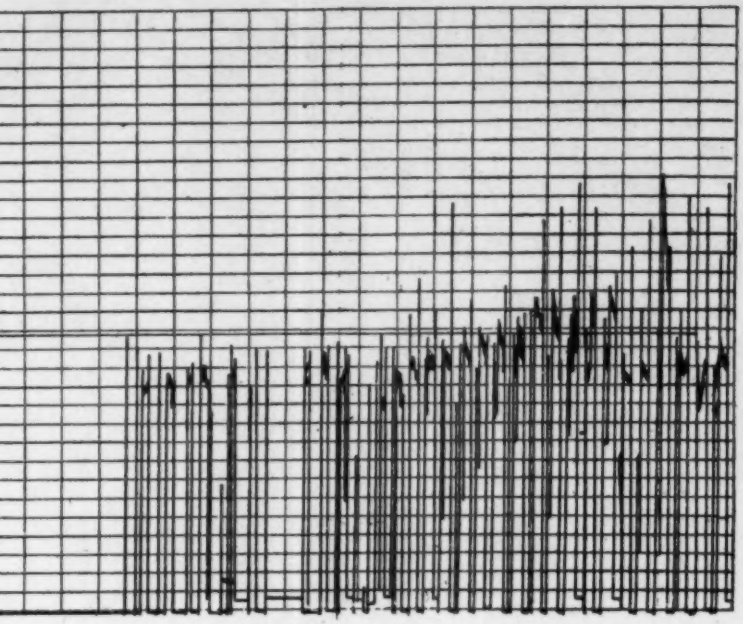
9 AM 8 AM

Lot No. 48227 S-3 Westinghouse Recording Instrument. Circuit N



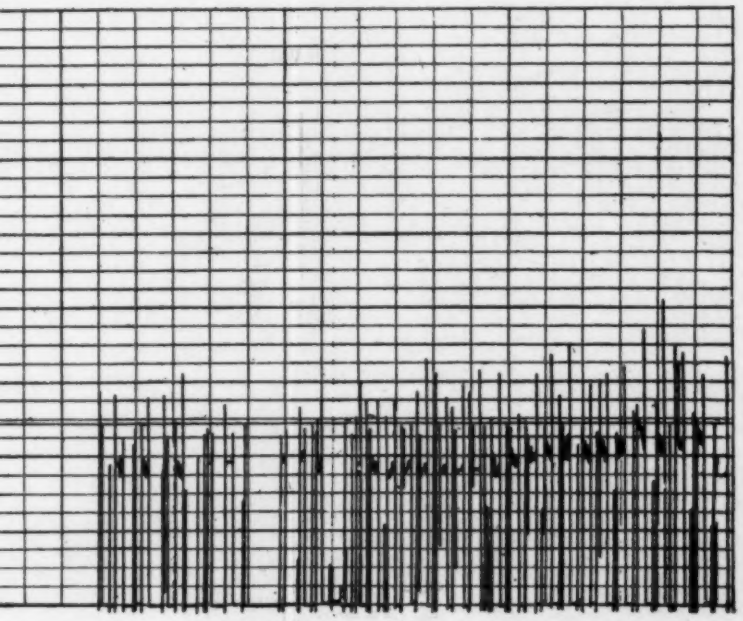
9 AM 8 AM

ent. Circuit No. WELL 1280 No. 2 MOTOR. Chart Style No. 84646-C. Date 2-9-28.



7 AM 6

ent. Circuit No. WELL 980 No. 1 MOTOR Chart Style No. 84646-C. Date 2-9-28



7 AM 6

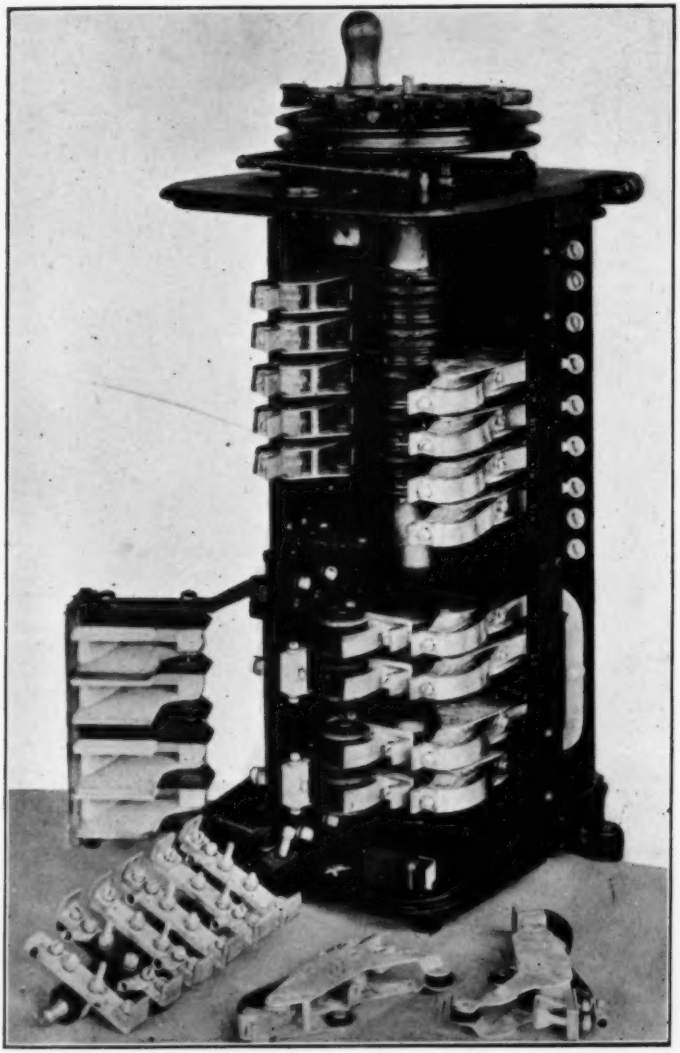


FIG. 11.

MODERN TYPE OF CONTROLLER.

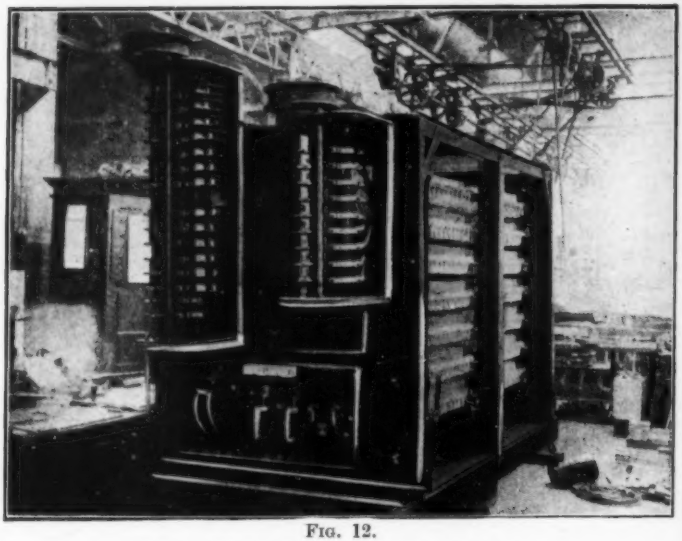


FIG. 12.

BRITISH EQUIPMENT FOR ROTARY DRILLING.

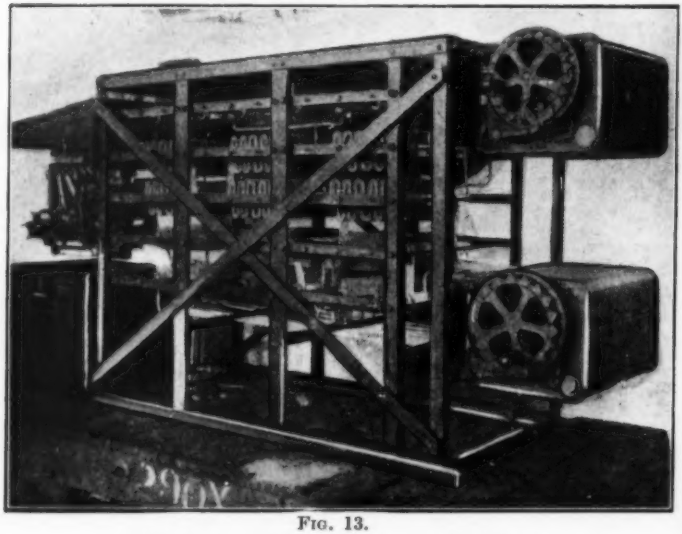


FIG. 13.

AMERICAN EQUIPMENT FOR ROTARY DRILLING.

provides a more flexible adjustment for retrieving the bit at any depth of hole.

Cable Tool Drilling.—The earliest application of electricity to cable tool drilling was a 75 H.P. single-speed motor with a controller and sub-dividing auxiliary controller to give speed adjustment. The electrical engineers of the Westinghouse Company of U.S.A., however, realised the need of a special type of equipment that would give a drilling motion equal to that of the steam engine and better than that obtained by the single-speed motor. The single-speed motor is still tolerated, but its performance cannot be compared with the twin motor drive as developed by the Westinghouse Company.

In performance and economical operation this type of equipment has proved itself.

Wells can be drilled in less time and at less cost than with any other form of power. Tools can be pulled quickly, taking less time away from actual drilling. Starting, stopping, reversing and close speed adjustment can be controlled instantly from the derrick floor. The equipment assures perfect motion at all depths of hole, because of the wide speed range available due to the particular method of control. The snappy stroke is easily obtained by virtue of the low inertia of the rotating parts due to their small diameter. Inherent, also, is a wide range of power for all the different operations, such as fishing, baling, pulling casing and dressing bits. In other words, slow speed and light pull or high and heavy pull, or any combination necessary for any operation. While twin motor cable tool equipment is preferred in most cases, the use of one two-speed motor is often found practical. The standard high-power pumping motor of 25/65 H.P. equipment with a sub-dividing controller makes a highly efficient drilling unit for wells within the limit of its capacity.

Auxiliary Drilling Equipments. Slush Pumps.—Single-speed motors with the modern type of mechanical contactor controller and standard ratings of 50, 75, 150, 200 H.P., are employed with belt gearing or gear chain drives. The gear chain drive combines the flexibility of the plain belt and the compactness of the gear drive.

Band Wheel Drive Combination Rigs.—A standard two-speed motor with controller and a 5 to 1 speed reduction gear, mounted on a combined bed plate on slide rails, the gear shaft being coupled to the band wheel by sprockets of chain, forms a compact and reliable equipment.

Metres.—It is not always possible for those in charge of drilling to follow the operations at each well as closely as may be desired.

As an auxiliary to electric drilling graphic metres may be furnished for recording the load under all conditions of operation. These instruments record a log of the wells from a time and power point of view.

Inclinometers.—The electrically operated inclinometer is a very useful accessory to the drilling department. As it is lowered down the hole the indicator on the surface indicates continuously the deviation of the hole from the vertical, and on the return journey check observations can be taken. Unfortunately, however, the instrument has not yet been sufficiently perfected to include an indication of azimuth bearings of the deviation, but in the author's opinion the bottom of the hole can be demarcated more satisfactorily by the application of directional radio equipment.

Righouse Heaters.—These heaters of 10 K.W. capacity serve the purpose of clothes drying rack and stove for cooking. All live parts are enclosed to prevent accidental contact, and a safety power switch of the oil-immersed type is provided for gaseous fields.

Well Pumping.—No other phase of operation on the fields gives more concern and warrants more consideration than well pumping. It is the heart of the industry, and calls for equipment having consistent performance. For large and important wells the two-speed standard pumping motor and equipment of 10/25, 12/30, 15/35, 20/50, 25/55 and 25/65 find a wide application.

The low H.P. low speed side is, of course, used for pumping, and the high H.P. high speed for cleaning, tube pulling and re-drilling. With the sizes available it is possible to make efficient selections, especially so when the large or parent well operates adjacent smaller wells by means of jerk lines.

For light shallow wells requiring infrequent cleaning the single-speed, squirrel cage motor with self-contained geared pumping jacks forms an efficient equipment. The usual standard sizes range 3, 5, 7½, 10 and 15 H.P. This type of equipment, of course, requires a portable equipment for the cleaning of the wells, the cost of which must be offset against the lower first cost of the squirrel cage motors compared with two-speed motors.

Pumping Powers.—Where the contour of the field permits and the location of wells is unscattered, centralised pumping powers form the most efficient and economical arrangement.

The most suitable motors are the special squirrel cage type with high torque starting windings or the auto-synchronous type of motor.

Automatic Pumping.—When wells are equipped with individual motors the automatic features of central control should receive serious

attention. Pumping is started and stopped at predetermined times by time-switches or by supervisory control from a production control centre. In the event of a well "going off" during its pumping time the motor is automatically stopped, thus reducing maintenance costs by eliminating hammering of the pump valves, rods, etc.

Gas Protected Type Equipment.—Opinion as to the form of protection on gaseous fields is somewhat divided between oil immersing and flame proof ventilation of metal enclosing boxes. However, collieries having given a lead the tendency is toward flame-proof enclosing.

Oil Treating Plant.—The electrical process of removing water and emulsion from oil has been very effective. The water content in the cleaned oil is reduced to at least 2 per cent. The process is briefly as follows :—

A large gas-tight tank is so constructed that oil passing through it must pass through an electric field. In passing through this field the emulsion is broken up into oil and water, which flow out at the top and bottom of the tank respectively.

Lighting.—Flood lighting is the most effective form of field lighting, and incidentally is very safe on gaseous fields. The system is very flexible, and allows of groups of lamps being located to the best advantage or transported from place to place to suit the activities.

Powerful searchlights mounted on special rigs at strategic places sweep the fields with their beams of light at nighttime, thus reducing petty theft to a minimum and assisting in the location of fires, etc.

Pipe Line Pumping.—During recent years many of the changes have been revolutionary, the full effect of which is not generally realised.

On account of their high operating speed centrifugal pumps are very suitable for electric motor drive by direct coupling. The use of this type of pump is an accepted practice and has proved very successful.

Motor-driven centrifugal pump stations have a very low first cost and maintenance cost. They require little attention and have a consistent performance. Reciprocating pumps may, of course, be used with synchronous motors or squirrel cage motors, but they entail expensive gear reductions by auxiliary gear, not to mention their comparatively low efficiency and high maintenance costs.

The foregoing is an indication of what has been done on the Burma fields, and has proved satisfactory in the conditions obtaining on that field ; but it will be realised that when considering electrification

of fields in other parts of the world, a careful study of the conditions obtaining must be made. There are so many factors ruling the application of electricity that unless the scheme is visualised as a whole the overall efficiency may be seriously impaired.

In conclusion the author begs to record his thanks to the Burmah Oil Company for permission to make use of their data in connection with oilfields electrification, and to acknowledge with appreciation the assistance given him by the Westinghouse and General Electric Companies of America, the British Thomson-Houston Company, the Metropolitan-Vickers Company, and Messrs. Babcock & Wilcox of Great Britain.

The Use of Steel in the Oil Industry with a Special Reference to Heat-resisting Steels.

By Sir ROBERT HADFIELD, Bt., F.R.S., M.Inst.C.E., and S. A. MAIN, B.Sc. (Hons.), F.Inst.P. (The Hadfield Research Laboratories, Sheffield, England).

SYNOPSIS

I. INTRODUCTION.
II. WELL-BORING AND PUMPING.
Importance of Using the Best Steel with the Correct Handling.
Quality of Steel.
Forging.
Temperature Colours of Heated Steel.
Heat Treatment.
Normalising, Hardening by Quenching, Quenching and Tempering.
Alloy Steels.
Vanadium Steel, Chromium Steel, Intermediate Manganese Steel, Steel for Jars, Manganese Steel.
III. MANUFACTURING PROCESSES.
The Need for Special Steels.
Characteristics of Heat-resisting Steels.
Steels for the higher ranges of Temperature above a red heat.
Resistance to Sulphurous Gases and Fumes.
Steels for the range 400°—600° C.
Specialised Types.
Non-corrodible Steels.
IV. CONCLUSION.

LIST OF ILLUSTRATIONS.

1. Carbon Steel of Analysis C. 0·42, Si. 0·20, Mn. 0·80 per cent. in its condition as Forged. Grain Size 1500 per sq. in.
2. 0·74 Carbon Steel heated to 1060°, and rolled at the same temperature.
3. 0·74 Carbon Steel heated to 1060°, cooled to 950° C. before finishing and rolling at 570° C.
4. Carbon Steel of Analysis C. 0·42, Si. 0·20, Mn. 0·80 per cent. Quenched from 900° C. in Oil. Reheated to 670° C. and Cooled in Air. Grain Size 125,000 per sq. in.
5. "Intermediate Manganese" Steel, C. 0·36, Si. 0·25, Mn. 1·76 per cent. Slowly Cooled from 870° C., then Reheated to 790° and again slowly cooled.
6. Tensile Specimens tested at 800° Centigrade.
7. Specimens heated in a Furnace Atmosphere for 100 hours at 950° Centigrade.
8. Recuperator Tube Castings.
9. Large Castings in "Era" Heat-resisting Steel.
10. Muffle for Enamelling of Iron Ware.
11. Cast Pyrometer Protection Sheaths in Heat-resisting Steel.
12. Hearth Bricks and Rabble Teeth for Zinc Roasting Furnaces.
13. Grate of Mechanical Stoker for Marine Boiler constructed from Castings of "Era" Heat-resisting Steel.

SECTION I.

Introduction.

In common with most other engineering industries, steel enters so largely into the construction of oil plant, and economic results are so much dependent upon its use in the most efficient manner, that some observations to the latter end from the steel manufacturer's side may be of use at this present Congress.

Metallurgical knowledge has within recent years advanced considerably and shown how to obtain greatly improved service from steel as compared with that obtainable previously. Formerly steel to the engineer was steel, and he thought he knew its capabilities and limitations pretty thoroughly. Such progress as he was able to make therefore, was mostly by careful design and mechanical ingenuity, with the intention often of circumventing such limitations. To-day when a particular component does not give satisfactory service, he may well consider how the desired performance can be obtained by attention to the selection and handling of the steel.

With the alloy steels also which are now available the modern engineer in fact has an inestimable advantage over his predecessors, because constructions and appliances of a utility which they could not dream of are made accomplished facts, owing to the remarkable service which alloy steels can perform in particular directions. To take one example, present day tramway systems in our large cities rely absolutely in many cases upon the use of the extraordinarily hard wearing Manganese Steel for the points and crossings at the more congested portions of the system. It is extremely doubtful whether engineering ingenuity, with only ordinary steel as available in the old days, could have successfully coped with this particular problem, and achieved the ready transport of so many millions of human beings in their daily avocations.

It seems probable, as indicated in the paper, at any rate as regards oil refining processes, that alloy steels will play a special part in their further development, and even as regards well-boring and pumping, it may well be that there too an intelligent knowledge of their capabilities may lead to greater productivity. In the oil industry, as in every other, it is therefore of importance for the engineer to keep himself thoroughly up-to-date with the progress which the steel metallurgist is making. The industry however, specially as far as the field operations are concerned, is from geographical considerations not able to keep in such close touch with metallurgical developments as are many others more favourably located. It is hoped that the present paper will assist towards that end.

SECTION II.

Well-boring and Pumping.

The oil industry divides itself, and is best so divided for the purpose of the present paper, into its two distinct branches, firstly the production of the crude oil, and secondly, the refining and separation of the latter into the various grades as required for commercial use. Well-boring and pumping are essentially mechanical operations, and the properties called for in the steel are mostly those of a mechanical nature, such as cutting qualities, tenacity, toughness or resistance to abrasion. On the other hand, the refining of oil is chemical and physical in character, and for some components additional and special properties are called for in the steel. These will be referred to in more detail in a later section.

Dealing in the first instance with the well-boring operation, it should be said at the outset that no attempt will be made here to give any guidance as to the selection of the right type, *i.e.*, composition, of steel for a particular component, except as regards the comparatively limited use of alloy steels. To do so would occupy far too much space, and practice, so far as it can be, with the plain carbon steels which form the bulk of the steel used, is now fairly well standardised, and the suitable specifications are readily accessible to those engineers who are not well informed in a particular instance. More often, however, the engineer will know quite well the particular type of carbon steel to employ, and in fact, have arrived, from his own experience, at the best practice to suit his own special conditions. A particular bit steel, for example, which an engineer may find suitable at one place may differ widely from that which gives best results in another formation at the same, or in another well.

The paper is best devoted, therefore, in the case of the carbon steels, to more general observations as to quality rather than type, and the handling of the steel in the field.

Importance of Using the Best Steel with Correct Handling.

As a first consideration there can be no doubt whatever that for all components it is economically sound to employ only the best quality of steel, obtained from reputable firms. Also, to ensure that any heating or manipulation necessary at the oil plant itself is carried out by a uniform and correct practice, with the necessary equipment to this end. To go still further, the authors would even recommend that the official responsible for the working of the steel should have had some metallurgical training.

The supplies of steel to many oil wells are carefully controlled, and the equipment for the handling of them all that should be desired. There are on the other hand many where the economic benefits to be obtained from a proper understanding of steel and its capabilities, are not fully appreciated. The general considerations pointed out here may therefore serve a useful purpose.

In many branches of engineering the steel can be supplied ready for use without further heat treatment, the operations by the user merely consisting of machining. In such cases the steel maker is willing to be fully responsible for the quality. If the firm is one of repute, confidence is well placed in them, because metallurgical knowledge among the best steel firms has reached a high order, and their equipment is thoroughly up-to-date.

In a great many cases, however, specially where steel is supplied for tools, forging and heat treatment operations have to be carried out on the steel by the user. The latter in general has not the same metallurgical knowledge as the steel maker, and cannot therefore get the best results from the steel. He may in fact in some cases obtain only a third rate performance from a steel which, handled with proper knowledge, is capable of giving unrivalled results in its particular job. These considerations apply specially to well boring, because here, owing to the great loss of time involved by replacements, the price paid for inferior performance is excessive ; or to put it the other way round, a superior steel correctly handled, even if at an appreciable advance in cost, easily pays for itself in greater continuity of working. This, of course, is specially the case with steel for bits and cutters.

Quality of Steel.

As regards the actual quality of the steel this is, as mentioned, a matter for which the steel maker himself is responsible, but it is well for the engineer to understand why the best is most economical. The characteristics of high grade steel of any particular type are firstly, that the composition and manufacturing routine are accurately controlled, and therefore the same for repeat batches. Without this the user cannot expect to get regular results, even if exercising the greatest care himself in his manipulation of it. A second feature of high grade steel is its purity, that is, freedom from injurious impurities, and general cleanliness.

Perhaps one of the most useful results of metallurgical science has been in establishing the benefits of attention to this question. It is now clearly understood that fractures in steel from whatever cause, if not actually provided with a starting point by the presence of inclusions, are more easily propagated by their means.

Thus in the case of drill bits and other cutting tools, hardness is a necessary characteristic, but not the only one. Attrition of the edge, and rapid wear of the hardest steel can easily occur if at the same time there is not the necessary cohesion to prevent the particles forming the edge easily breaking away. Impurities are inimical to such cohesion, and consequently a high grade steel is able to give a much better performance.

To take an example, in the kind of rock drills used in quarrying and metalliferous mining, and using carbon steel of an ordinary grade, with about 0·04 per cent. sulphur and phosphorus, the maximum carbon percentage must be limited to about 0·75 per cent. To endeavour to use steel of higher temper only results in the drills chipping and breaking away too freely at the edge. With high grade steel, on the other hand, the carbon percentage may quite safely be carried up to 0·85 per cent., thus enabling harder rock to be dealt with successfully. The higher grade steel also has a further advantage in that it is less susceptible to breakages in the hardening operation due to the expansion or contraction strains set up, whether by uneven heating or in quenching—a not infrequent cause of waste.

As showing the high standard of quality now obtainable, the results of analyses of a continuous series of heats of their "Hecla 19" Drill Steel made at the works of the authors, indicate that the average contents of the two elements, sulphur and phosphorus, taken together, is under 0·030 per cent. This not over a short period, but over many months' working.

While much of the steel forming oil well plant is not used in a hard condition, it is nevertheless true that the purest and cleanest steel gives also for other components such superior results as to fully justify its use generally in preference to inferior grades. Apart from greater ductility and resistance to shock, which give a greater margin of safety, there is in the higher grade of steel a marked superiority in resistance to failure by what is known as fatigue, to which some components, for example, sucker rods and pins, are specially subject. Failure by fatigue, as is now well known, occurs through steady propagation of a crack through the steel, and research has clearly indicated that its progress is greatly facilitated by being able to pass from one inclusion to another.

Forging.

It is principally as regards the forging and heat treatment of steel where metallurgical knowledge is essential on the part of the user, and if the present paper can do anything to help to impress the importance of the correct handling of the steel in these operations, it will have achieved something. Much of the infor-

mation given is no doubt common knowledge in the steel industry, but it cannot be too generally known by the users themselves.

Referring more specifically to plain carbon steels, although the remarks also apply in a more general way to alloy steels, it can be taken as a general principle that the best results are obtained with a fine grain structure, and—apart of course from quenched steel where the carbon is, or should be, in solution—with the carbide finally and evenly distributed. The natural tendency in carbon steel is however for the carbide to agglomerate into comparatively large masses (large that is from the point of view of the microscopist), taking the form of "pearlite," and leaving the remaining iron to form large "ferrite" crystals as in the photomicrograph Fig. 1. Fracture through such a structure is comparatively easy, and this is particularly true of fatigue fractures. The "ferrite" breaks down on its slip planes, and where the grain size is large the progress of the fracture is little restricted or retarded owing to the comparatively few grain junctions.

The risk of overheating and "burning" of the steel in the forging operation is one with which the forgeman soon becomes acquainted, because the appearance or crumbling of the steel make it evident. There are however, other less obvious but still detrimental results which accrue without overheating the steel to this extent.

Although it is not the direct intention, it should be realised that in the forging operation the steel inevitably receives a heat treatment and undergoes changes of structure which are dependent upon the degree of heat applied, and the temperatures at which the steel is worked. The photomicrographs Figs. 2 and 3, obtained in the course of a special rolling experiment well illustrate this. These are of the same drill steel of 0·74 per cent. carbon, and the billets were in both cases heated to 1060° C. preparatory to rolling. The difference is in the actual temperature at which the steel was rolled. In the case of Fig. 2 the billet was rolled directly it was taken out of the furnace, that is, at 1060° C. The other billet represented by Fig. 3 was allowed to cool outside the furnace to 950° C. before it was put through the rolls, *i.e.*, so that the rolling should be completed by the time a black heat was just reached (about 570° C.). The much finer and more desirable structure of the latter is clearly visible. Although rolling or forging at such low temperature is not advocated because of the strains set up, it is clear that variations of rolling or forging temperature, even although below that resulting in "burning" of the steel, have a distinct effect on the internal structure and properties of the steel, although the forgeman has no indication of this. Here may in fact suitably be acknowledged the great help which the microscope

has given and continues to give on such questions, particularly in regard to carbon steels, the clear features of whose structures make them an excellent subject for the microscope.

Thus from the point of view of obtaining the most desirable internal architecture or microstructure, the lowest practical forging temperature is desirable. A lower limit, however, is set by another consideration, that is, the production of strains in the steel if the temperature is too low. Forging must in any case be completed at above the "critical temperature," round about 700° C., where the carbon comes out of solution on cooling and the steel entirely changes its internal structure, so as to take advantage of the readjustment which goes on internally at this temperature. So long also as the finishing temperature is above this point there will also be sufficient temperature remaining in the steel itself to allow of the strains caused by working to readjust themselves, an opportunity which is not afforded if the work is carried down until say the steel is black. The critical temperature varies with composition of the steel, and should be ascertained.

The practical operation of this knowledge naturally involves a fairly close control of temperature in the forging operation, and the necessary equipment to that end. Practical men are, it is to be feared, many of them still rather shy of employing the pyrometer, and take some pride in their ability to judge temperatures by eye. The complete elimination of such methods, although desirable, will probably not be achieved just yet.

Temperature Colours of Heated Steel.

Recognising this, one of the authors (Hadfield) prepared, and exhibited at the World Power Conference held at Wembley in 1924, a temperature colour chart, which it is believed reproduces better than any previous efforts he has seen, the colours of steel when heated to successively increasing temperatures up to 1600° C. The chart was produced by co-operation between the pyrometric staff at Hecla Works, Sheffield, and a competent artist, through observation of furnaces heated to various temperatures. One of the difficulties experienced is in producing printed reproductions of such colour charts with the correct colour values, and this had special attention. Those interested will find the chart reproduced in the Proceedings of the Conference mentioned.

These temperature colours must not of course be confused with the temper colours, ranging from yellow to purple, formed on a bright surface of steel when it is heated to comparatively low temperatures, *i.e.*, up to about 350° C.

Heat Treatment.

The particular heat treatment with which the user is mainly concerned is the quenching of the bits or cutters, but a measure of heat treatment of another kind is also required subsequent to forging operations of any kind, that is, what is known as normalising.

Normalising.

However well the forging may have been carried out, strains are left in the steel, greater in proportion as the work is larger. Such strains in the case of a bit, which in any case has to be subsequently heated for hardening, may, as they often do, lead to fracture during this heating owing to additional expansion strains then imposed. A careful heat treatment or normalising after forging is therefore desirable, and consists in heating the forging to a temperature above the critical point, taking care to see that the heating is slow and uniform through the lower range of temperature where the risk of cracks due to expansion are greatest. The cooling from the maximum temperature can quite conveniently be in air.

It might be considered that with the same care taken in heating for hardening, the risks of breakage would be avoided without the introduction of an intermediate heating such as this. The hardening operation as usually carried out, however, does not provide sufficient time for such thoroughly careful heating.

In any case as regards the bit shank, and for other components which have not to be hardened after forging, in which is included such operations as setting up, it is highly undesirable to put them into service subject to forging strains. Normalising, besides removing the strains, also effects fuller refinement of the structure than can be obtained under the best forging conditions.

Hardening by Quenching.

While the risk of cracking of bits in hardening may, as mentioned, be minimised by a previous normalising treatment, the greatest care should always be exercised both in the heating and in the manner of quenching during hardening.

The arguments for such careful procedure in both the forging and the hardening operations are well described in the report issued by the United States Bureau of Mines, Serial No. 2712, in October, 1925. This is entitled, " Temperature Control System for Dressing and Tempering Fishtail Bits," and written by Charles H. Shapiro. Briefly, in the hardening operation, without proper care or suitable equipment, unequally rapid heating occurs at different parts of the bit, with consequent strains which, if of

sufficient magnitude, lead to fracture. In quenching also, the rate of cooling can be unequal in different parts with the same results.

As regards heating, unless a salt or lead bath is used, the care necessary consists mainly in ensuring that heating is not unduly hurried, so that any tendency for one part to become hotter than the rest is evened up by conduction. Also in movement and turning over of the bit in the furnace so that no portion receives localised heat of the flame more than the others.

In quenching, the chief point is to see that the tool is well agitated in the water or oil, so that the quenching effect is equal at all points or, better still, to have the liquid itself in vigorous circulation.

The question of the precise quenching temperature is also important, because any temperature in excess of that necessary causes a larger crystallisation with consequently less durability without increasing the hardness obtained. The best quenching temperature is therefore just above the "critical" temperature, which varies somewhat with different types of steel, and when ascertained it should unquestionably be controlled by pyrometer. Herein lies a further advantage of the lead or salt bath, because the pyrometer can be conveniently applied to it so as to give accurate indications. When heating bits in a flame furnace it is difficult to use a pyrometer in such a way as to determine their true temperature.

In the quenching operation again, control of the temperature of the bath must be exercised. The volume of liquid must at any rate be sufficiently large so that the repeated quenching of bits in it will not raise its temperature appreciably, but still more effective control, where the amount of work put through is large, should be provided by circulation of the liquid, water or oil, through a cooling system.

The report mentioned gives the record of systematic tests intended to ascertain the comparative performance on the one hand of bits heated for hardening on ideal lines, *i.e.*, in a liquid bath with pyrometric control, and alternatively, of bits hardened by ordinary methods. Results show a marked superiority for the former, working in all types of formations, both in footage and drilling speed, and are such as to leave no doubt as to the real economic value of proper equipment and control in this operation. As a general average the footage of the bits hardened under temperature control was 13 ft. 1½ in. comparing with 8 ft. 6½ in. without such control, an increase of 53·66 per cent. The rate of drilling was 13 ft. per minute and 9 ft. 11½ in. respectively, an increase on this count of 30·54 per cent.

Quenching and Tempering Treatment.

The fullest measure of toughness and resistance to fatigue is conferred upon carbon steel by a heat treatment which consists of a quenching from above the critical point and subsequently heating to some temperature below it ; that is what is known as a quenching and tempering (or drawing) treatment. By this means a specially fine crystalline structure and distribution of carbon is obtained, as seen in Fig. 4. This can be contrasted directly with Fig. 1, being from the same steel. As compared with the same material, annealed or normalised, this treatment confers not only a higher tenacity, but greater toughness as shown by the following test data :—

Steel	Treatment.	Yield point. tons per sq. in.	Maximum stress.	Elong'n. %	Reduction of area. %	Izod Impact value. ft. lbs.	Brinell hardness.
C. 0·42 Si. 0·20 Mn. 0·80	As forged (Fig. 1)	25	45	22	45	20	180
„	"Normalised" i.e., cooled in air from 850° C.	24	43	25	45	25	180
„	Quenched in oil from 900° C. Tempered at 670° C. (As Fig. 4).	30	48	26	55	45	217
C. 0·55 Si. 0·20 Mn. 0·80	Normalised	25	48	18	35	8	217

The toughness is also, it will be seen, superior to that of a normalised or annealed carbon steel of higher temper with similar tenacity. For parts therefore which are subject to heavy strain, and where the existing material is not fully equal to its duty, it is often preferable to use a similar steel in a quenched and tempered condition, rather than to simply increase the tenacity by an increase in carbon percentage. For such parts as sucker rods, where fatiguing stresses are specially experienced, quenching and tempering treatment has been adopted with success.

This type of treatment is not one which the operators at the plant are called upon to carry out, as it only concerns those supplies of steel which are purchased in the condition in which they are to be used. It requires careful control, but competent steel firms are fully equipped for its operation, and can be relied upon to obtain the best possible results from it. The benefits derived from this treatment in fact should be considered in all specially difficult cases, that is, where too frequent replacements occur owing to breakage, and, until they are utilised to the fullest possible extent, may in general be regarded as a sort of reserve which carbon steel has, before the necessity arises of employing special steels.

Alloy Steels.

In general the use of alloy steels obtains its justification usually from one of two main reasons. Either they enable a performance to be accomplished which is not possible of attainment with ordinary steel—there are many examples in modern engineering industry where performance is absolutely dependent upon the use of alloy steels—or that the economic results are better than those obtained with ordinary steel. So far as alloy steels have been employed hitherto in well boring, it has been mostly on the latter ground.

The greatest scope for improvement is probably in the cutting tools since a harder steel than now obtainable is very desirable for dealing better with the harder rocks and formations. There is here apparently therefore a good opportunity for the use of alloy steels in place of the present carbon steels now used. It is a curious metallurgical fact however, that, notwithstanding the many desirable characteristics which have been conferred upon steel through the means of alloying, no alloy steel has yet been discovered which exceeds or quite equals in its hardness that obtainable with plain high carbon steel in its suitably quenched condition, and from the point of view of hardness alone the latter remains unrivalled. Certain alloys, both ferrous and non-ferrous, of a particularly hard character are, it is true, available, and made use of in a special way as mentioned later, but are not workable and cannot of themselves be made into bits or other tools.

The possible advantages of alloy steels therefore in this particular direction are very much limited. It is the fact however, that the fullest advantage of the hardness obtainable with carbon steel cannot always be utilised because of its brittleness, and consequent chipping or fracturing away of the edge. It is, on the other hand, characteristic of certain types of alloy steel that, although they may not attain the same intense hardness as carbon steel, such hardness as they do possess is accompanied by much improved toughness as compared with carbon steel of similar hardness.

For this reason various attempts have been made to improve oil drilling bits and cutters, and in fact drill steels for quarrying and metalliferous mining, by the addition of small quantities of alloying elements, for example, of vanadium and chromium. These additions are comparatively small in quantity—only about 0·20 per cent. of vanadium, or up to 0·60 per cent. of chromium—so as not to seriously reduce the mineralogical hardness attainable, in the expectation that the improved toughness and cohesion conferred would on the balance provide an edge which in practice will be more lasting.

Such claims are in fact made for both types of steel and no doubt against certain types of rock, upon the nature of which

comparative performance so much depends, their use as compared with carbon steel is beneficial. Typical analyses of such steels are, in the case of vanadium steel :—Carbon 0·80, Silicon 0·14, Manganese 0·30, Vanadium 0·20 per cent. With chromium steel, the amount of the chromium addition varies somewhat between 0·20 and 0·60 per cent., a higher carbon content being possible with the lower chromium. Thus Carbon 0·45/0·50, Silicon 0·10/0·20, Manganese 0·50/0·60, Chromium 0·40/0·60 per cent. represent a composition quite frequently employed in oil well drilling, and a steel with Carbon 0·70/0·75, Silicon 0·20, Manganese 0·50/0·55, Chromium 0·25/0·35 also finds favour for some classes of work. Many hundreds of tons of steel of the former type under the brand No. " Hecla 104 " have been supplied by the authors' firm for oil well drilling bits with satisfactory results.

Intermediate Manganese Steel.

To the same end considerable use is also made of a type of steel known as Intermediate Manganese Steel, that is, a steel containing comparatively low carbon 0·35/0·40 per cent., but with the addition of 1½ to 1¾ per cent. of manganese. In a sense this is an alloy steel, the manganese percentage being increased appreciably over the quite moderate proportions found in ordinary carbon steels. It is not, however, generally classed as such, and its chief advantages come from its much more refined structure, as compared with carbon steel of rather high carbon and of equal tenacity, although the carbides are more manganiferous in character, and the true alloying effect of the manganese cannot be ignored.

The superior mechanical properties thus obtained from Intermediate Manganese Steel are exemplified in the following figures. The two steels have been heat treated in the same way, and with as nearly as possible the same hardness and tenacity, the plain carbon steel shows its inferiority specially in a lower Yield Point, and in toughness as indicated by the Izod test.

The heat treatment consisted of a slow cooling from 870° C., followed by a further heating to 790° and slow cooling, this heat treatment in fact being of a type which is often applied to the Intermediate Manganese Steel intended for fishtail bits.

Yield point.	Maximum stress.	Elong'n.	Reduction of area.	Izod impact value.	Brinell hardness.
tons per sq. in.		%	%	ft. lbs.	
Intermediate Manganese Steel :— C. 0·36, Si. 0·25, S. 0·015, P. 0·027, Mn. 1·76					
30·4	46·1	26·0	53·6	66, 56, 57	187
Carbon Steel :— C. 0·67, Si. 0·09, S. 0·016, P. 0·013, Mn. 0·27					
23·8	44·5	23·5	44·6	6, 6.	176

With this type of steel a Brinell hardness is obtainable on the cutting edge, by quenching, of 550 to 575, and its use is therefore

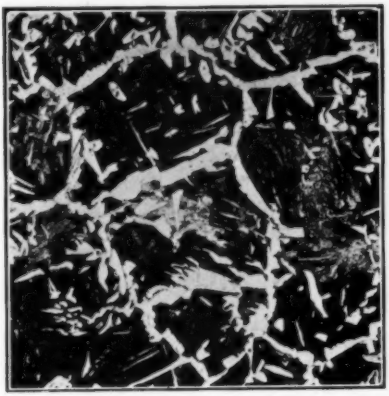


FIG. 1.

Magnification 50 diams.

Carbon Steel of Analysis C. 0·42, Si. 0·20, Mn. 0·80 per cent. in its condition as forged.
Grain size 1,500 per sq. in.

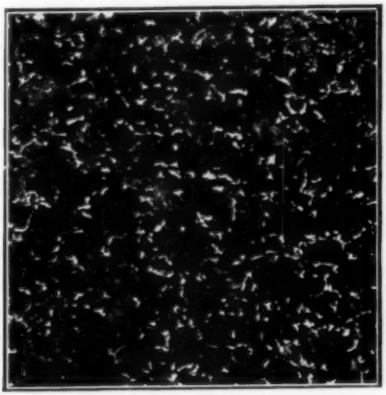


FIG. 2.

Magnification 100 diams.
0·74 Carbon Steel heated to 1060° C., and rolled at the same temperature.

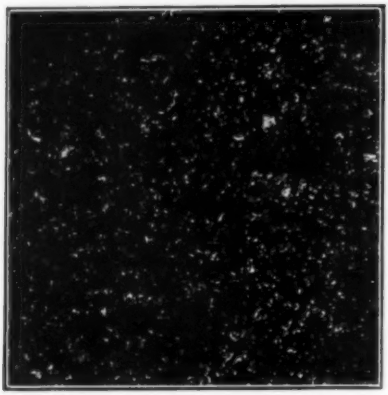


FIG. 3.

Magnification 100 diams.

0·74 Carbon Steel heated to 1060° C., cooled to 950° C. before finishing the rolling at 570° C.

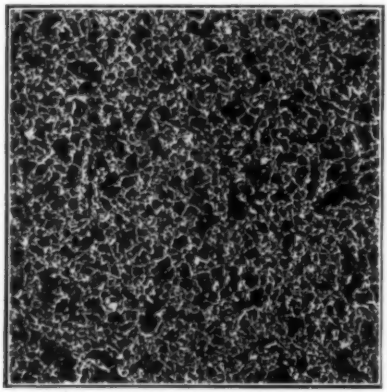


FIG. 4.

Magnification 50 diams.

Carbon Steel of Analysis C. 0·42, Si. 0·20, Mn. 0·80 per cent. quenched from 900°C. in Oil, reheated to 670° C. and cooled in Air. Grain size 125,000 per sq. in.

limited to those cases where the formations dealt with are not of a specially hard nature. Under these conditions however, the service it gives is found superior to that of ordinary carbon steel.

This type of steel is one which under their " Era 51 " brand has been manufactured for many years by the authors' firm, and used with success for a variety of purposes. Its excellent structure is shown in Fig. 5. In oil well plants also " Era 51 " steel is giving uniform satisfaction wherever it is used, *i.e.*, mainly for drill bits. In one case where employed for core barrel cutter heads, the customer reports that the results obtained were far better than with any steel they had been able to obtain previously.

The Use of Bits with Hard Cutting Material Welded-on or Inserted.

An interesting expedient, with the object of obtaining a specially hard and durable cutting edge for bits and cutters, has been adopted during the past few years, and, it is claimed, with some success. It consists of inserting into the edge of the bit or cutter various proprietary products, metallic or non-metallic, of great hardness, their attachment being effected usually by electric or oxy-acetylene welding. It is also claimed that worn tools can also be restored to their original form and dimensions by simply building on a fresh edge of these materials by the same means.

The idea is thus an adaptation from the original diamond drill, and rendered possible by the discovery of these substances having a mineralogical hardness of over 7 in Moh's scale, and in some cases over 9, *i.e.*, able to scratch Corundum. Supported in this way by the steel in which they are embedded, they are able to withstand the shocks of drilling operations without shattering.

The composition of these hard materials is mostly maintained secret, but it is understood that Tungsten and Molybdenum Carbides, alloys of Iron in which Tungsten, Chromium or Manganese are incorporated separately or together, or Cobalt-Chromium alloys form the basis of most of them.

The method however, naturally requires care and experience to ensure a sound job in every case, and it may be doubted whether such expert work can always be provided for satisfactorily at the plant. Nevertheless, any effective means which will result in harder and more durable cutting tools will be of so much benefit in oil well boring that it will be interesting to watch the further progress of this idea.

Steel for Jars.

The exacting duty to which these components are submitted, and their consequent liability to fracture, has always provided an excellent opportunity for just those characteristics of high tenacity

and toughness obtainable with alloy steels. The fact however, that until comparatively recently the form of construction involved welding, prevented the effective use of alloy steels. With the introduction of the weldless jar this difficulty is removed, and excellent service can now be obtained from jars made from nickel-chromium-molybdenum steel, the tensile and shock resisting properties of which are indicated in the following table, which represents data obtained from the steel of this type known as "Hecla 116" manufactured by the authors' firm :—

Yield point. tons per sq. in.	Maximum stress.	Elong'n. %	Reduction of area. %	Izod impact value. ft. lbs.	Brinell hardness.
54	64	23	62	80	280
66	74	19	60	70	315
80	86	16	54	30	375

As will be seen, by variations in heat treatment, that is, the tempering temperature, the tenacity of this steel can be varied within fairly wide limits and adjusted so as best to suit the different character of the work to be performed in different plants. It is found to give results superior to those obtained from plain nickel-chromium steel.

Manganese Steel.

The remarkable and outstanding abrasion resisting properties of manganese steel, meaning the alloy containing about 12 per cent. of manganese and 1¼ per cent. of carbon, discovered by one of the authors (Hadfield), which have proved of such immense benefit in many other branches of the engineering industry, find also their application in oil well plant, specially for the wire line sheaves, of which large numbers have been supplied by the authors' firm in this steel under their "Era" brand.

A further use is for drive chains and sprockets, where the excessive wear otherwise experienced, is thus prevented.

SECTION III.

MANUFACTURING PROCESSES.

The Need for Special Steels.

The various refining processes to which the crude oil is submitted for the separation of its valuable constituents form a splendid field for research, and the endeavours of many chemical engineers are directed towards the evolution of new or more efficient processes. In this respect the oil industry is participating in the enormous

development of chemical and physical processes generally, which forms such a prominent feature of technical progress at the present time. Much of this progress comes from a recognition of the advantages of high temperatures and pressures in chemical processes, and there is more than a tendency in the oil industry, as in other branches of applied chemistry, to carry out operations at increasing temperature, or pressure, or both.

So long as the temperatures did not exceed about 500° C. (900° F.) and pressures were comparatively low, the steel or iron piping and vessels necessary served quite well. Any attempt to push temperatures beyond this, specially if accompanied by increased pressure, necessitatcs the use of a steel which has not the disadvantage of ordinary steel or iron of losing its strength at a red heat, or becoming badly oxidised by the air or furnace gases so as to waste away. In the absence of anything better than ordinary steel, in fact, it is difficult to see how chemical engineers could make practical use of the knowledge which they possess as to the advantages of high temperature processes.

Fortunately however, there are at his service, as the result of contemporaneous progress by the metallurgist, special steels having remarkable properties in their resistance to heat, both as regards the maintenance of a high strength and resistance to chemical attack at temperatures well above a red heat.

Characteristics of Heat Resisting Steels.

These characteristics are well exemplified in Figs. 6 and 7 which display the properties of the steel known as "Era/HR" Heat Resisting Steel in contrast with those of ordinary steel. In Fig. 6 are shown two test pieces which have been broken under tension while at a temperature of 800° C. One of these which is of ordinary steel, has required a load of only 6¼ tons per square inch to break it. This of course illustrates what is generally known as to the softening of ordinary steel at a red heat. At ordinary temperatures the breaking load of such steel is 30 to 35 tons per square inch, so that it has lost four-fifths of its tenacity. The other specimen is of "Era/HR" Steel and at 800° C. its tensile strength is 24·6 tons per square inch, nearly four times as much as that of ordinary steel.

Fig. 7 gives a similar parallel as regards "heat scaling." When exposed to a furnace atmosphere for 100 hours at 950° C., ordinary steel exhibits the familiar appearance shown by the specimen on the left, having become very badly oxidised or scaled. The other bar, which was of the same form and dimensions, is of "Era/HR" Steel. Beyond the formation of a slight surface film it has suffered no wastage.

Steels for the Higher Ranges of Temperature above a Red Heat.

In several other industries the use of special heat resisting steels has already made great headway, and many processes and plants are now being operated which, without their aid, would be impracticable. Those concerned in developing new processes in connection with oil refining may therefore be interested to read some examples of what has been done in other directions. Although perhaps they may not be interested in the particular plant or process there concerned, these examples will illustrate the kinds of problem which have been solved by the use of heat resisting steels, and also some of the different forms in which it is possible to produce them.

The requirements in various cases differ greatly, and the characteristics desired, besides those of strength at high temperatures and non-scaling properties, may include the provision of the steel in a particular form, such as cold drawn tubes or even wire. It should be realised that from the very fact of their possessing superior strength at high temperatures, difficulty arises in the hot working of all kinds of heat resisting steels ; most of them also have the property of hardening considerably under cold work, which makes their cold working specially difficult.

Some types are, however, better to work than others, and in most cases, by a selection of a suitable type of steel, perhaps with some sacrifice of properties which are really non-essential, the requirements can be reconciled and the particular problem solved. Specialised types have also been produced where, for example, non-scaling properties have been developed to the highest possible degree. Although not possessing the fullest measure of strength at high temperatures, and in some cases are even of a rather brittle character, these have nevertheless proved extremely useful where non-scaling properties are of first importance.

Fig. 8 shows recuperator tube castings, the function of which is to effect preheating of the air supply to a furnace, the air passing through them and being heated by the waste gases which pass outside. Since the temperatures attained are well above a red heat, and ordinary steel or cast iron are therefore out of the question, fireclay tubes have formerly been used for this purpose, in spite of their obvious disadvantages, specially in the low efficiency of heat transfer due to their low thermal conductivity. Fireclay tubes are also liable to crack and cause leakage, and are fragile. With "Era" Heat Resisting Steel these disabilities are removed, giving a robust and efficient recuperator.

These tubes further illustrate the excellent casting qualities of the heat resisting steel employed, the acstings being of a difficult

character and very thin in section, only in fact $\frac{1}{16}$th inch in thickness at the edges of the fins, yet the material runs perfectly.

The steel used for this purpose is of the type developed for all-round purposes and standardised under the designation of "Era H.R.1." It combines to the best advantage the characteristics of strength at high temperatures and non-scaling properties, an indication of which was given in Figs. 6 and 7.

The familiar elastic nature found in steel at ordinary temperatures is lacking in all metals at any temperature above a red heat, and they become viscous. The measure of strength of metals at high temperatures is therefore in reality a measure of their viscosity. Given sufficient time, and provided the load is above a certain limit, depending on the metal and the particular temperature, the metal will continuously stretch under tensile stress until it breaks. The greater the load, the sooner it will break. Practical testing therefore is directed to determining the tensile load at which the continuous stretch or "creep" as it is called, goes on at such an extremely slow rate as to be of no practical consequence. The stress arrived at is called the creep stress limit. It becomes less as the temperature increases. For any particular temperature this creep stress limit figure forms a criterion for comparison of the strength of one heat resisting material with another.

Actually, owing to the impracticability of determining really ultimate limits, which would require many months or even years for each separate determination, comparisons are made on the basis of the small but definite rate of creep. This in the authors' laboratories amounts to one-thousandth part of 1 per cent. of the gauge length per hour. On this basis the creep stress figures for "Era/H.R.1" are as follows :—

Temperature °C.	Creep stress. tons per sq. in.
600	9
700	6
800	$2\frac{1}{2}$
900	$\frac{1}{4}$

These figures may at first sight appear somewhat low, but they really represent a striking achievement, and a strength which is quite adequate for many purposes. When it is remembered that ordinary steel at 800° C. fails to support a load even of $\frac{1}{2}$ ton per square inch without continuous stretching, finally breaking in 107 hours, and that cast iron will break under even $\frac{1}{4}$ ton, the true extent of this advance is better appreciated. "Era/H.R.1" Steel, with suitable tools and with a suitable practice, is machinable.

Quite large castings weighing about 3 tons each in this steel

are illustrated in Fig. 9. The two upright castings are 3 inches in thickness and are reaction vessels for a Bergius Coal-Hydrogenation Plant. The coal substance is converted into an oil having the consistency of tar at a temperature of nearly 500° C. (930° F.), and a working pressure of upwards of 3000 lbs. per square inch.

It should be mentioned in passing that the catalysing action of ordinary steel upon hydrocarbons, which in some processes has been rather a bugbear, is not experienced with the new heat-resisting alloy steels, or at any rate only to an insignificant extent.

" Era/H.R.1 " Steel has been applied to the reaction vessels in which coal is subjected to the action of compressed hydrogen under a pressure of 150 atmospheres at 450° C., and suitable materials are available for the construction of the retort, when the economic position of the industry makes extensive commercial development possible.

" Era H.R.1 " Steel is also used successfully for parts of tar distillation plants, including heater tubes for tar stills. In one case the pipes carrying hot combustion at temperatures ranging from 950/1250° C. (1740/2280° F.) have lasted nearly a year of continuous working.

The ribbed casting in Fig. 9 is for use in a special high temperature process for the reduction of ores.

Wherever possible, in those cases where the special properties of " Era/H.R.1 " Steel are called for, it should be used in the form of castings. Forgings can however, be made from it where the construction does not permit of castings, and although naturally more expensive there have been many cases where the advantages derived from the use of " Era/H.R.1 " Steel forgings have fully justified the expenditure.

It so happens however, that there are many applications where strength at high temperatures is not of such vital importance. A type, therefore, of steel known as " Era/H.R.2 " has been developed which, while retaining to the full the non-scaling characteristics of " Era/H.R.1," can be more readily forged, and even provided in the form of rolled sheets suitable for making built-up constructions, either by welding or rivetting, such as that illustrated in Fig. 10. This is a muffle 9 ft. 6 in. in length built up from plates $\frac{1}{2}$ inch in thickness, which are rivetted together, and is intended for the enamelling of ironware. It is important in this process that no scale shall flake away from the muffle, otherwise it would cause discolouration of the enamelled articles, and " Era/H.R.2 " Steel amply fulfils this requirement, because the very slight film of scale which forms upon it is quite adherent.

Although, as mentioned, not equal to " Era/H.R.1" Steel in its strength at high temperatures, by comparison with ordinary steel

" Era/H.R. 2 " Steel is in this respect superior, as in fact are all the heat-resisting steels subsequently referred to. The creep stress figures for " Era/H.R.2 " Steel are as follows :—

Temperature. °C.	Creep stress. tons per sq. in.
600	8
700	5
800	2
900	¼

Resistance to Sulphurous Gases and Fumes.

" Era/H.R.1 " and " Era/H.R.2 " Steels are of the high percentage nickel-chromium type, and a special feature which has been considered in their development has been resistance to sulphurous furnace atmospheres which are particularly destructive in their effects on some types of otherwise excellent heat-resisting steels. Notwithstanding that they contain nickel in their composition, which in fact helps to give them the excellent toughness they possess, these steels behave excellently in sulphurous atmospheres. Cast pyrometer protection sheaths of " Era/H.R.1 " Steel, as illustrated in Fig. 11, are regularly used in oil-fired furnaces in the authors' works at a temperature of 950/1000° C. and have a life of upwards of 18 months.

To accommodate the range of " Era/H.R." Steels further to the requirements of industry another special type has been developed, known as " Era/H.R.4." There are many applications where castings are quite suitable, and while resistance to heat scaling is of prime importance, special strength at high temperatures is unnecessary, nor even ordinary toughness, that is in the cold. The non-scaling properties of " Era/H.R.4 " Steel are in the ordinary way equal to those of " Era/H.R.1 " or " Era/H.R.2," and where specially sulphurous conditions are experienced, are even superior, because of the absence of nickel from its composition. This absence of nickel renders the castings somewhat brittle, but for many purposes, as mentioned, this does not matter. Fig. 12 illustrates such a case and represents hearth bricks and rabble teeth of which large supplies have been made for furnaces for the roasting of zinc ore. Here the steel has met with considerable success under conditions which are quite hopeless for many otherwise good heat-resisting steels not specially directed to meet the special problem caused by sulphur.

Fig. 13 is of special interest because it illustrates an application which only the use of " Era " heat-resisting steel has made practicable, that is the use of mechanical stokers operated with preheated air, on cargo carrying vessels. The photograph shows one of the grates, of the Erith-Roe type, of the Canadian Pacific

Steamship Company's vessel "Beaverford" after 12 months service, and is built up from castings of "Era/H.R.4" Steel. As seen in the photograph, the grate is in excellent condition. When cast iron parts were used replacement was necessary after every second round trip. In this particular case the conditions were not specially sulphurous, but as the general characteristics of "Era/H.R." Castings were quite suitable for the purpose and they are rather less expensive, it can be used for this reason with advantage, in place of either the "Era/H.R.1" or "Era/H.R.2" types.

"Era/H.R.4" Steel is forgeable and the production of hot rolled tubes is also practicable. Use has been made of the latter in an experimental plant for oil refining in which the temperatures have reached 950° C. with complete success, and for the further practical exploitation of the process the use of tubes of this steel has been decided upon.

Recently an additional type, known as "Era/H.R.4 S" has been added to the range of alloys made by the authors' firm, and has altogether remarkable non-scaling properties. Like "Era/H.R.4" it can be forged, but the castings in this steel are somewhat brittle. It is, however, able to sustain long continued service at temperatures as high as 1100° C., without appreciable wastage due to scaling, and even higher temperatures up to 1200° C. for shorter or intermittent periods.

Steel for the Range 400° to 600° C.

There is an important field for the use of special steels of a heat resisting character in which the working temperatures range between about 400° and 600° C. This is specially the case in steam practice owing to the advances in working temperature, but also in other industries.

At about 400° C. ordinary steel first shows a propensity to creep under load, and rapidly becomes weaker with increasing temperature. The highly alloyed heat resisting steels previously referred to are, of course, able to display remarkable strength in this region of temperature which, for them, is comparatively low, but since heat scaling troubles are not seriously experienced below about 600° C. even with ordinary steel, the non-scaling properties of the highly alloyed heat resisting steels would more or less be wasted.

In these circumstances there have been developed further types of heat resisting steel which, while having no special claims to non-scaling properties, show a marked improvement on ordinary steel in their strength in the temperature range 400° to 600° C. They are at the same time less expensive than the more highly alloyed "Era/H.R." Steels. Also, although true elasticity such as is found in steel in the cold, cannot be expected in this temper-

ature range, these steels have greater pretentions to the possession of a high elastic limit and yield point.

The steel known as "Hecla 116," which is of the nickel-chromium-molybdenum type, has at 450° C. a creep stress limit of 17 tons per square inch, at 500° C., 8 tons and at 550° C. 6 tons. Its characteristics under the ordinary tensile test, both at ordinary temperatures and when hot, are excellent, as shown by the following figures :—

Temperature.		Proportional	Y.P.	M.S.	El.	R.A.	Izod.	Brinell.
°F.	°C.	Limit.	tons/sq. in.		%	%	ft. lbs.	
60	15	52	54	64	23	62	80	280
1,000	540	*21	25	43	27	50	—	—

* Rate of loading 15 seconds per ton.

The precise rate of loading in the test carried out at 1000° F. (540° C.) is indicated because this influences the figure obtained for the proportional limit from any steel tested at such a comparatively high temperature.

A further excellent feature of "Hecla 116" steel is that it is completely free from the trouble experienced with some alternative steels of becoming brittle under the influence of repeated heating and cooling. It has proved of special value for such purposes as the flange bolts of the steam pipe line in up-to-date high temperature installations. In this connection the coefficient of thermal expansion of the steel employed is of importance in the following way. A steel with a coefficient appreciably higher than that of the steel in the flange causes the bolt, when at the working temperature, to become slack. If tightened at temperature, then on cooling large shrinkage strains are caused in the bolt. Certain types of steel are precluded for this reason. "Hecla 116" Steel has a coefficient substantially the same as that of ordinary steel.

With the research efforts which are continuously being made in this field of heat resisting steels, progress is taking place rapidly, and quite recently a new type of steel known as "Era 131" has been developed, which shows considerable promise. Complete data are not yet available for publication, but it can be said that while having the same strength as "Hecla 116" at high temperatures it has the advantage of lending itself to the production of solid or hollow castings, also forgings, and can be provided in the form of cold drawn tubes.

Specialised Types of Heat Resisting Steel.

Although the applications of heat resisting steel have little connection with the oil industry, they will serve to demonstrate, where problems of special importance are met with, that it is worth while to develop specialised types of steel best suited to the particular kind of service demanded.

The erosion and corrosion of steam turbine blading, and the loss of efficiency which it leads to, have long been tolerated to a much greater extent than economic consideration can really justify. This is because until comparatively recently no material was available having in itself all the characteristics necessary in turbine blading, including resistance to erosion and corrosion. With advance in steam temperatures the problem has become further accentuated and a material with definitely heat resisting characteristics has become essential.

Without going into detail it may be said that the famous French firm, Société Anonyme de Commentry-Fourchambault et Decazeville, of Imphy, paid special attention to this problem, and as the result developed the special alloy known as " ATV," which it can be justly claimed solves completely all the difficulties hitherto met with in connection with turbine blading, and further, places in the hands of the engineer a material which can be relied on for service at the highest steam temperatures, actual or prospective. Turbines of over one million and a half horse power capacity have already been equipped with blading of this steel. This material, under the name of " Hecla/ATV," is manufactured by the authors' firm, in collaboration with Messrs. The Fourchambault Company, under the combined patents and manufacturing experience of the two firms.

Finally, in the development of the aeroplane the service to which the exhaust valves is subjected has become increasingly severe, until with the most advanced types of aeroplane at the present time, unless a special steel of altogether extraordinary heat resisting characteristics was available, continuous running of the engine would not be possible. Fortunately by collaboration between the French firm mentioned and the authors' firm, Messrs. Hadfields of Sheffield, a specialised type of steel known as " Era/ATV " has been developed, which is able to meet all requirements. The full story of the experimental work leading to the adoption of this steel is an interesting one, but would require too much space here. It has been referred to by the authors in others of their published papers.

As indicating the merits of this steel it may be said that valves of " Era/ATV " Steel have been employed in all the recent successful and outstanding attempts on speed records, whether on land, water or in the air. This refers particularly to the British Supermarine Napier S5, which with a speed of 281 miles per hour won the Schneider Trophy in 1927 ; also the similar machine which equalled in November last at Calshot the world's speed record of 319 miles per hour. Coming to land performances, both Sir Henry Segrave's " Golden Arrow," and Captain Malcolm Campbell's " Bluebird " were so equipped, as was the winning Bentley Car in the 1929

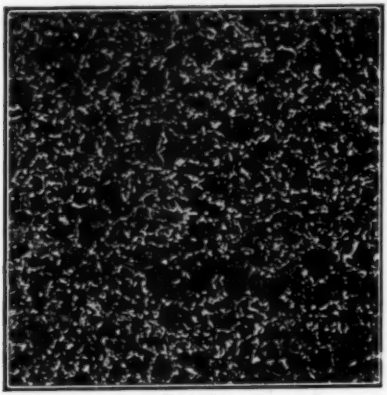


FIG. 5.

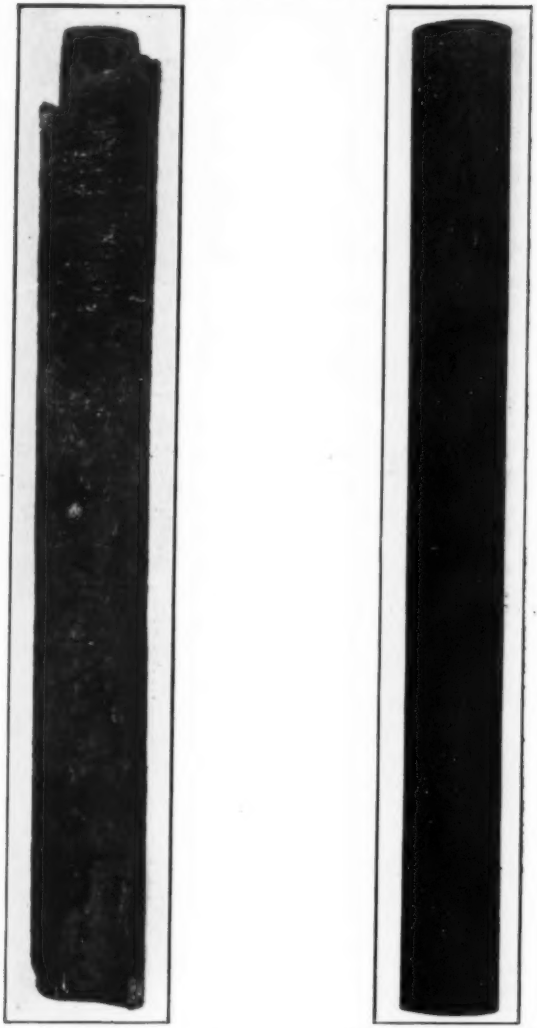
Magnification 100 diams.
"Intermediate Manganese" Steel. C. 0·36, Si. 0·25, Mn. 1·76. Slowly cooled from 870° C., then reheated to 790° C. and again slowly cooled.

TENSILE SPECIMENS TESTED AT 800° CENTIGRADE.

Ordinary Steel.		"Era H.R." Steel.
	Tensile Strength.	
6·5	Tons per square inch.	24·6
76	Elongation per cent.	36
	Reduction of Area	
90	per cent.	60

FIG. 6.

SPECIMENS HEATED IN A FURNACE ATMOSPHERE FOR 100 HOURS AT 950° CENTIGRADE.



Ordinary Steel.
Loss by Scaling, 33 per cent.
(A portion of the Scale has been broken away.)

"Era" Heat-Resisting Steel.
Loss by Scaling, nil.

FIG. 7.

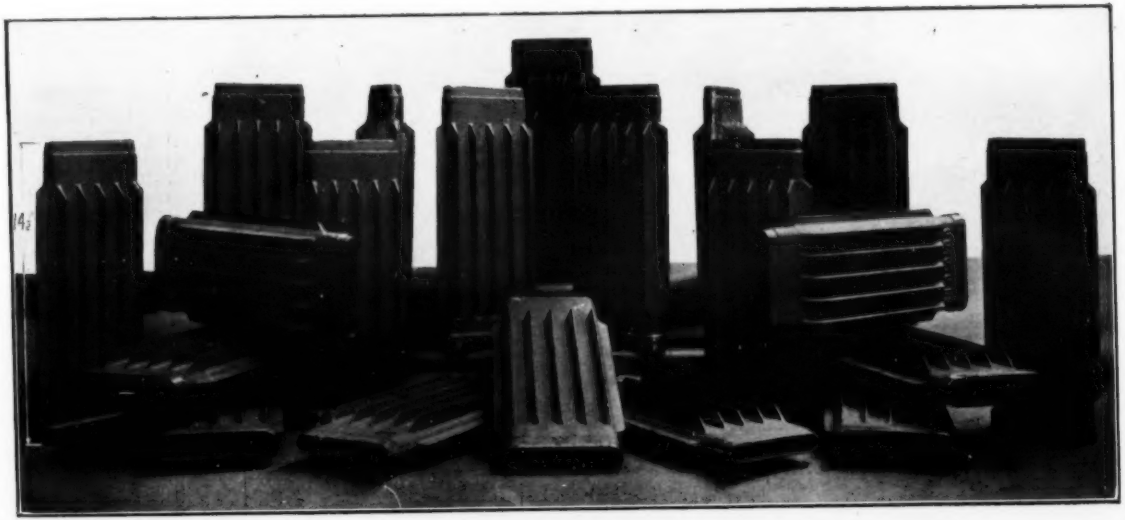


FIG. 8.

RECUPERATOR TUBE CASTINGS.

FIG. 9.

LARGE CASTINGS IN "ERA" HEAT-RESISTING STEEL.

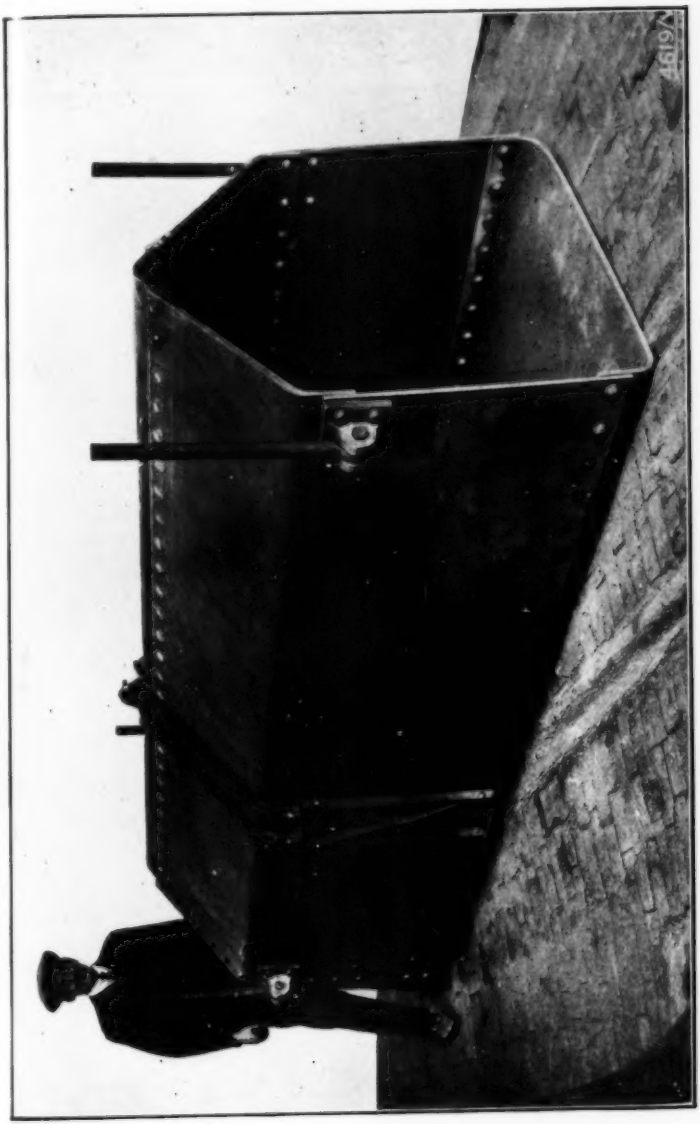


FIG. 10.

MUFFLE FOR ENAMELLING OF IRON WARE.

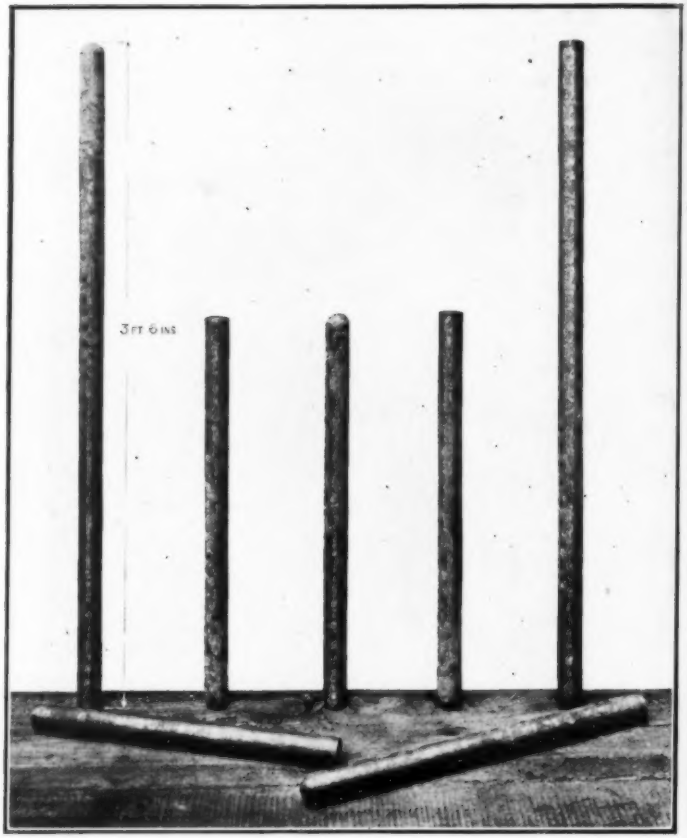


FIG. 11.

CAST PYROMETER PROTECTION SHEATHS IN HEAT-RESISTING STEEL.

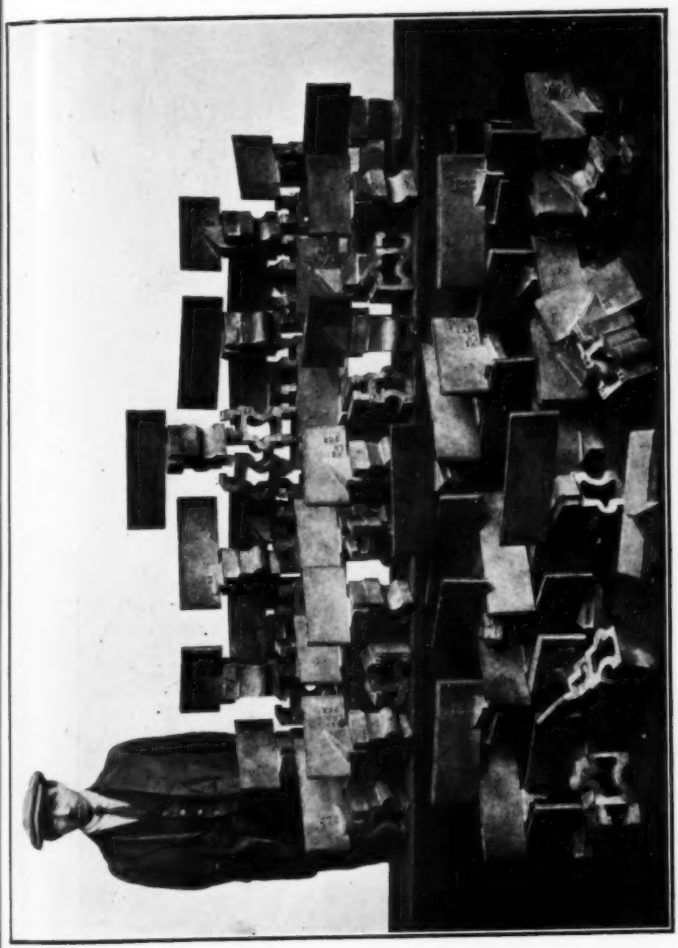


FIG. 12.

HEARTH BRICKS AND RABBLE TEETH FOR ZINC-ROASTING FURNACES.

FIG. 13.

GRATE OF MECHANICAL STOKER FOR MARINE BOILER CONSTRUCTED FROM CASTINGS OF "ERA" HEAT-RESISTING STEEL.

This photograph shows the grate after one year's continuous service, and the engineer reports that it is still in perfect condition. The cast iron parts previously used for the construction of the grate had to be renewed after every second round trip.
NOTE.—The somewhat rough appearance of the grate is due to adhering clinker, the metal underlying this being in perfect condition.

Grand Prix d'Endurance at Le Mans; finally, Sir Henry Segrave's motor boat "Miss England," with which he holds supremacy on the water.

The examples given are limited in number, and could have been added to very considerably if space permitted. They will, however, it is hoped, have served to give some indication of the special uses of the new heat resisting steels in modern engineering, and to show how far they are likely to assist in the development of oil refining processes.

Non-corrodible Steels.

As with heat resisting steels, so progress of a very marked kind has been made in the production also of non-corrodible steels, and the subject is one on which much could be usefully written. Any account of these non-corrodible steels to be of value would however require much further space. Reluctantly, and to keep the present paper down to reasonable dimensions, the authors have therefore had to exclude any special reference to them.

Nevertheless, the corrosion problems which are met with in oil refining plant, and exist, perhaps to a lesser degree, in the oil field, must give the engineer an interest in these new steels. The authors therefore hope to have an early opportunity of presenting a paper which will deal with non-corrodible steels, to one of the technical societies connected with the oil industry.

Suffice it to say that non-corroding steels of high quality are now available. It is true they are not cheap steels, but where they can be properly employed there is no doubt, notwithstanding the higher cost, their use is economical. One of the writers of this paper is a member of the Sea-Water Corrosion Committee of the Institution of Civil Engineers, where excellent work is being done. Whilst in this case the problem is somewhat different, information of high practical value has been accumulated, which should be of service in connection with other branches of engineering.

SECTION IV.

Conclusion.

In conclusion, the authors would emphasise the importance of close collaboration between the user and the steel maker in all questions of special importance where steel is employed. It is only from the combined knowledge of the plant designer, or manager, who knows what he wants, and the steel maker who understands the characteristics of his steels, that the best results are to be obtained. This is particularly true of the special heat resisting steels referred to in Section III. It is in this way that the already large and increasing use of these steels and the benefits derived from them, have been best facilitated.

GRATE OF MECHANICAL STOKER FOR MARINE BOILER CONSTRUCTED FROM CASTINGS OF "ERA" HEAT-RESISTING STEEL.

This photograph shows the grate after one year's continuous service, and the engineer reports that it is still in perfect condition. The cast iron bars previously used for the construction of the grate had to be renewed after every second round trip.

NOTE.—The complete smokelessness of the grate is due to adhering clinker, the metal underlying this being in perfect condition.

CORRESPONDENCE.

Bagdad, 31.7.29.

DEAR SIR,—Re Paper by Parker and Southwell, 12.2.29 on the Chemical Investigation of (Trinidad) Well Waters.

In the examination of Persian well waters about three years ago the writer found notable quantities of ammonia. The waters were brines of varying concentration at depths from 1,000 to 3,000 feet.

The following were some typical results for ammonium ion in parts per million :—

"Free."		"Combined."		Total.
180	..	100	..	280
90	..	10	..	100
—	..	—	..	180
—	..	—	..	150
80	..	130	..	210
—	..	—	..	30
30	..	180	..	210
160	..	310	..	470

In these analyses the "free" ammonia was determined by steam distillation of the original brine (into standard acid) and the combined ammonia by continuing the distillation after addition of alkali.

In some cases a further yield of ammonia was obtained when the cooled alkaline brine was reduced with aluminium foil and the distillation continued. This third figure had been provisionally calculated to "nitrate" as in ordinary water analysis, giving figures which ranged up to 140 parts per million of NO_3.

Search of available literature disclosed no previous records of ammonia determination in well waters.

The figures had no immediate significance for the geological department, and as the writer was not in a position to obtain sufficient correlated samples for research, the subject has not been pursued. It seems possible that systematic ammonia determinations might have value in the discussion of petroleum genesis, and their possible utility for the Fields geologist might be worth investigation.

Methods of analysis for routine work should preferably be standardised. What procedure, for instance, is to be adopted for the determination of carbonate ion in a sulphuretted brine containing ammonia? Distillation of the acidified brine in a current of CO_2-free air under a reflux condenser through a silver

sulphate tube, and collection of the CO_2 in a weighed potash bulb after drying through sulphuric acid would appear the only reliable method.

In recording results it is agreed that arbitrary conjugations of ions when we have no knowledge of the actual associations and equilibria are pointless and misleading.

Granted that ions should be separately returned, and not as salts, there is much to be said for the term "gram-equivalent" instead of the phrase "reaction equivalent." The former term has a wider appeal, shows the unit of measurement, and would be at once understood by any chemist.

Chase Palmer ("Geochemical Interpretation of Water Analyses," *U.S. Geol. Survey Bull.* 479), records actual or physical weights as a first column, "reaction coefficients" which are reciprocals of our "equivalent weights" (as ordinarily understood in chemistry) for multipliers in a second column, and the products as "reaction equivalents" (corresponding to our "gram equivalents") in a third column. The latter are then further expressed individually as percentages of their total, eliminating dilution disturbances in drilling in their effect on tracing the origins of the water.

"Gram-equivalents" (as ordinarily understood) can very conveniently be determined, however, as a first computation from the weighings and volumetric readings of analysis. A second column can show their relative percentages according to Chase Palmer's method. In a third column the "Equivalent weights" of the ions can be set down, giving by multiplication in a fourth column the actual or physical weights. Thus we have :—

1. Gram-equivalents per litre (or other unit vol.).	2. Do., as percentages of their total.	3. Equivalent weights of the ions as multipliers.	4. Actual weights of ions present.

The system is then immediately intelligible to anyone with elementary chemical knowledge, whereas the American expressions are not clearly significant except to specialists.

F. L. Bassett

(Consulting Chemist : Govt. Chemist, Iraq).

Sunbury-on-Thames, 2.10.29.

Dear Sir,

The fact that Persian Well waters contain a notable quantity of ammonium compounds is, of course, well-known to the chemists and geologists of the Anglo-Persian Oil Company, complete analyses

of various well waters in the Masjid-i-Suleiman area having been made in 1916 and the high content of combined nitrogen recognised. Similar comments were made by Mr. Bassett in 1922 in reporting to this Company the analyses of various Persian Well waters.

This relatively high content of ammonium compounds has also been noted in well waters taken from other parts of Persia, such as Naft Khana.

The existence of ammonium compounds in considerable concentration in Persian Well waters was recorded in a paper by W. H. Thomas (J. Inst. Petr. Techn, 1924, **10**, 210) though the quantitative analyses were not published.

It would certainly be of great interest in the discussion of the genesis of petroleum to learn if ammonia is present in quantity in all or nearly all waters which accompany petroleum.

F. B. Thole.
Anglo-Persian Oil Co., Ltd.
(Research Branch).

Ploesti, Rumania, 24.9.29.

Dear Sir,

In connection with your letter to us of May 22 last (in which you intimate that papers submitted for publication by Members of Branches shall be sent forward under the authority of the Branch concerned) we would like to draw your attention to the fact that the paper of Mr. McL. Drader (a Member of the Rumanian Branch) published in No. 75 of the Journal, was not so sent forward.

Your local Committee had no idea that such a paper had been submitted for publication ; had they had, they would unhesitatingly have advised you against its publication in the form in which it has appeared, owing to the misleading picture it gives of present conditions in the Oil Industry of Rumania.

In view of the careful scrutinizing which contributions from the Rumanian Branch appear to receive from your Publication Committee, we cannot imagine how this non-technical paper has slipped through so uncensored.

The author is unsufficiently informed as to recent conditions in Rumania, and many of his unqualified generalities give a quite wrong impression. For example, it is not the usual custom for companies to purchase second-hand material (page 459) : further, the author unfortunately makes statements of a most undiplomatic nature, *i.e.*, regarding the employments of local engineers by foreign

companies, in page 459, par. 5 and 6. We have a large number of Rumanian Members, who will peruse this paper with much interest, and feel a slight upon their ability (which is quite undeserved as most of them are in effective charge) and cannot fail to produce injured feelings.

J. E. TREACY.

Hon. Secretary, Rumanian Branch,
The Institution of Petroleum Technologists.

ERRATA.

WADE: MADAGASCAR AND ITS OIL LANDS.
(Jnl. 72, February, 1929.)

Pages 32, 33.—For BEMOLANZA read BEMOLANGA.

Page 33.—For INDO-MILANESIAN read INDO-MELANESIAN.

Page 2.—Top figure should read: Volcanic mass of ambohitrosy from the S. showing cones and craters.

Facing page 17.—Top picture should read: Gneissic plateau with worn-down granite dome.

REVIEWS.

Die Rumanischen Erdollagerstatten. By Karl Krejci-Graf. Vearlag von Ferdinand Enke in Stuttgart, 1929. Pp. 140+viii., with 43 text figures and folding stratigraphical table. 15 Marks.

In no other country during the last decade has the knowledge of fundamental geology of petroleum undergone such a marked revolution as in Rumania, thanks largely to the brilliant researches of an international alpine school and of those chemists and physicists who have laboured with the problems of salt dynamics. The working out of the Carpathian nappes, the meticulous care with which the essential palæontology, especially of the Pliocene deposits, has been pursued, and the unravelling of the sequence of salt intrusions, equally their tectonic significance, are performances of which the science may be justly proud. Yet in the face of all this it has been said, perhaps somewhat cynically, that geology in Rumania has come too late; that the record of oil-production since the annual barrelage first exceeded the million mark in 1899 is in itself a vindication of empirical methods of development and a triumph for the petroleum engineer as such. If we are to admit a belated entry of orthodox geology in this field, at least it is not inopportune nor without far-reaching consequence to future prospects, as this book, correctly interpreted, makes abundantly clear. The trend of oil-production in Rumania lies in two obvious directions: proving deeper sands in existing fields and locating new fields in areas which are structurally favourable. It is to modern conceptions of the stratigraphy and tectonics of the south-eastern Carpathian belt that we must look for the key to new developments, and Krejci-Graf's contribution will go a long way towards clearing the ground for further advance.

English versions of the essential geology of Rumanian oil-territory have appeared from time to time in recent years, both in periodicals in this country and in America. On the whole these contributions have been little more than outlines of the subject; for detail, an extensive foreign literature must be searched, though no one publication known to the reviewer covers the ground selected by the author so concisely and to such advantage. The title hardly indicates the whole purview of the work, for not only the oil-pools, but the complete suite of sedimentary deposits, their structures and peculiar features of the important fields, are treated very thoroughly. One gains a much clearer idea of the multiplicity of types of oil-occurrence, whether influenced by natural conditions of sedimentation, by purely structural factors, or by salt intrusions, from this essay than from many more elaborate expositions from other pens. We may take a few of the outstanding points at random.

Firstly, the diagrams: the author has used praiseworthy restraint with his "curves"; the cult of alpine geology is too often productive of those amazing "space-restorations" of the ideal geology, severely complex in design, abstruse in the mechanics involved. Here, with few exceptions, the figures depict the reservoirs associated with structures which are readily understood, and in which the fundamental stratigraphical factors are never lost sight of or swamped by the intricacies of intimate thrusting. We always suspected that some of the published sections of sub-surface conditions at certain of the Rumanian fields were products of fervid imagination; the author's more material interpretations go far in confirming that impression.

Apart from these, we commend particularly fig. 2, the Pliocene "facies" diagram, figs. 20 and 21, sketches of mud-volcanoes, the gas, oil and water diagram of Runcu (after A. Pustowka) of fig. 37, and the tectonic map (fig. 43). A very clear field-location map for both east and south-eastern territory is also included (pp. 120-1).

Relegated to a short appendix in the text, quite early in the book, is the controverted question of the age of the salt. The author is emphatic in his dismissal of Vojtestis's interpretation, *i.e.*, great antiquity, and declares that it cannot be older than Mesozoic; he agrees with Mrazec in placing it about Aquitanian times (Upper Oligocene), thus raising an interesting point relative to the South-west Asiatic occurrences.

For the most part the text comprises an orderly treatment of the subject in which facts and theories are sharply separated. About half the volume is taken up with a discussion of the different modes of occurrence of oil in eastern and in south-eastern Rumania, the contrast of oil-pools of the "foothills" and plateau, of salt-contacts and attenuated folds, and of the *Aufbruchsrand* (salt-contact with the "foreland") and what the author terms *Brachyantiklinen*, a peculiar type of "shortened" fold to which this name is quite appropriate. The second main section of the work seeks to co-ordinate the observations, is generally more discursive and, in some parts, speculative. It deals with the influence of tectonics on the oil-measures, on migration as determined by salt-developments (amply attested by asphalt occurrences), with conceptions of the mother-rocks involved, and so on. The summary, pp. 117-126, would have been improved had the author set forth his conclusions in short, numbered paragraphs, and not woven everything into a kind of detached essay; it is, however, valuable in drawing attention to the essential problems of Rumanian oil-geology. It surely would not have added much to the cost of the book if this summary had been translated into English for the benefit of many English-speaking operators in the country to whom German may present some difficulty in reading, apart from others abroad whose interest in Rumanian oil is considerable.

H. B. Milner.

"Le Petrole" (Petroleum). By J. Filhol and Ch. Bihoreau, in the "Collection Arista." Paris: Les Editions Pittoresques, 1929. Pp. 203. 30 Francs. With an introduction by Monsieur Louis Pineau, Director of the National Office of Combustible Liquids, Paris.

"The sole merit of this book," says Mons. Pineau, "will not merely be that it should bring the petroleum question to the door of a large general public, but it should be useful to specialists also to refresh their memories." Mons. Pineau thus very well describes the purpose of the book, which is essentially a popular manual, written in the French language very clearly, concisely and accurately, but not pretending to be a technical text-book. There exist a number of excellent English and American text-books of great value to Petroleum Technologists and students in the several branches in which they specialise. Most of the information in "Le Petrole" is available in English from various sources. There is, perhaps, however, no single handy volume in English in which so good a general popular view of the subject is given as is the case in the book of which we are now writing. "Le Petrole" is the kind of book therefore that should be of value to students of any nationality, as giving them a general preliminary survey of the industry in all its phases, and to other persons having a more general interest in oil.

A perusal of this book induces us to point again to the necessity that exists for consumers of oil, engine designers, Government administrators and others to make themselves acquainted with the groundwork and the general methods of the oil industry. Knowledge of oil matters has doubtless spread considerably in recent years, but may usefully be extended still further. Criticism is valuable in every industry in proportion to the groundwork of information on which it is based. In the oil industry in particular it is obviously essential that designers of mechanisms depending on oil for motive power or lubrication, should know within limits what can or cannot be done with different grades of oil products, and should therefore co-operate closely with oil producers. Every oil consumer also should have more explicit knowledge than a mere understanding that oil is not brought to the pump or the garage without the expenditure of much capital and brain labour of men of science and of technical and commercial experience.

In the book under review the processes relating to exploitation and field work are first described, and information is then given as to the distribution of petroleum over the world. There are a number of maps and illustrations of a useful character. The treatment which the crude oil undergoes is dealt with as well as the means of transport, storage and sale. The chapters that follow next, viz.: VI., VII., and VIII., will have a special interest for many readers, English as well as French, who are concerned with the political and economic rôle of petroleum, or who wish to know something about the rise of the great oil companies of the world and developments of French oil policy in particular. Finally there are notes as to the future of the petroleum industry. We learn that France before the war lagged behind the U.S.A. and Great Britain in her recognition of the important part which petroleum was destined to play in the industries of peace and in the operations of war on land and sea and in the air.

The authors tell us in a judicial and matter-of-fact style what France has done to make up "lee-way," particularly in the direction of a participation in the fields of Irak, and in the regulation of imports into France to take advantage of various competing sources of supply. We are told of the French production of Pechelbronn and of what has been done to utilize power alcohol and benzol, and also, in heavy vehicles, of a gas obtained from charcoal. The use of substitutes for, or supplements to, "essence" (*i.e.*, motor spirit) has not reached large dimensions, but the French Government has stimulated effort in that direction by exemption from, or reduction in, taxes on vehicles in certain cases.

We give ourselves the pleasure of reproducing here a brief summary of the concluding paragraphs of Chapter VII. ("French petroleum policy"), and we make our bow to our French friends in acknowledgment of their kindly recognition of British foresight in petroleum policy:—

Chapter VII., Pages 177-8.

"In conclusion: France before the war had ignored the importance of petroleum and had given it no place in its policy . . . It is only just to recognise that France has since then profited by experience. She has had to improvise her arrangements and has not yet fully made up for lost time. In putting her hand to the work she has found the majority of the important oil positions occupied by nations which have shown greater foresight. In the domain of petroleum, the U.S.A., thanks to the riches lying beneath its soil and the power of its great oil concerns, and England, thanks to the foresight (clairvoyance) of its Admiralty and the shrewdness of its policy, have secured the lion's share. France, however, has obtained a good place for the future alongside these Powers and has made advantageous use of circumstances since the war. Some of the other European Continental nations are paying France the compliment of adopting a somewhat similar policy to hers."

F. W. BLACK.

THE GAS AIR-LIFT POCKET BOOK. Robert Stirling. London: E. and F. N. Spon, Ltd. 1929. Pp. 95.

In a very handy form the oil operator is given a concise and very practical description of the production of oil from boreholes by the application of compressed air or gas. It is essentially for the practical oil operator and, besides useful formula reduced to its simplest form, which should enable any engineer to install a plant of this description, gives examples of the most readily accessible method of keeping the information with regard to individual wells. Actual results of operations are given.

This book amplifies and supplements the information given in the author's valuable paper on the subject read before the Institution of Petroleum Technologists in 1920 and published in their Journal.

It is perhaps to be regretted that more space has not been allotted to the method of dealing with, and preventing, emulsions of oil and foreign matter.

WILLIAM SUTTON.

PETROLEUM VADEMECUM. R. Schwarz. Berlin, Verlag fur Fachliteratur, 1929. 20 Marks.

This well-known handbook has now reached its sixth edition, having been revised and brought up-to-date. It is divided into three separate sections, each having its pages numbered separately, and contains a mass of information likely to be useful to the petroleum technologist.

The first section, containing 136 pages, consists of conversion tables for petroleum weights and measures, specific gravity, viscosity, physical and chemical data. The headings of the tables are printed in German, French and English, and this section should prove of considerable value in facilitating the conversion and comparison of the various units used in the industry.

The second section sets out the tariff rates on mineral oils in various countries, and has apparently been revised in accordance with the latest ordinances. This chapter occupies 175 pages.

Statistics of the world's petroleum industry are given in 249 pages of the third section. These statistics include the production of crude oil in various countries, together with particulars of imports and exports of petroleum products, and in the majority of cases include the returns for the year 1928. Included in this section are also small scale maps of various petroleum harbours

GEORGE SELL.

BOOKS RECEIVED.

THE FUSION POINT OF COAL. Part I. J. G. King, A. Blackie and J. O'N. Millott. Fuel Research Paper No. 23. London: H.M. Stationery Office. Pp. iv., 20, with 7 Figs. 1s. net.

The determination of the fusion temperature of coal ash is of increasing practical interest, and in the past determinations by different observers have shown differences due to the technique adopted. The Fuel Research Station, in co-operation with the U.S. Bureau of Mines, have made an investigation to ascertain whether conditions could be prescribed to obtain concordant results in different laboratories. The results obtained are considered to be satisfactory. The effect of the furnace atmosphere on the fusion point was also considered, and it was found that when heated in a mildly reducing atmosphere the fusion of an ash may be 200° C. lower than when heated in an oxidising atmosphere.

REPAIRS TO DIESEL ENGINE PARTS BY ELECTRO-DEPOSITION. C. H. Faris. London: Diesel Engine Users' Association. Pp. 25, with 9 Figs. 7s. net.

This is a paper read before the Association on June 14, 1929, together with a full report of the discussion and the author's reply.

CHEMICAL BIBLIOGRAPHIES. National Research Council Bull., No. 71. Washington, D.C. $1.50.

The National Research Council announces the publication of its Bulletin No. 71, which is the First Supplement to the Bibliography of Bibliographies on Chemistry and Chemical Technology covering principally the period 1924-1928, Bulletin No. 50 having covered the period 1900-1924. This Supplement contains approximately 4100 bibliographies classified under 1050 headings. The original Bulletin (No. 50) contained approximately 10,000 bibliographies classified under 2400 headings.

As the title indicates, the work (as in the case of Bulletin No. 50) is a compilation of bibliographies published as separates, or at the end of books or magazine articles, or as footnotes to the same, on the numerous aspects of pure and applied chemistry. Each entry gives name of author or compiler, title and place of publication. The majority of the entries state the number of references, thus giving an indication of the completeness of the particular bibliography. The entries are classified under the proper subject-headings, alphabetically arranged. The duplication of individual entries has been largely avoided by the liberal use of cross references.

As an example of the value of this compilation, the following information is given regarding the number of bibliographies reported in Bulletin No. 71 for some of the more important topics:—

Blood Chemistry 25, Cement 21, Coal 31, Colloids 55, Dielectrics 24, Dyes and Dyeing 27, Fertilizers 38, Fibres 26, Foods 33, Iron and Steel 76, Metabolism 77, Milk 43, Mineral Resources 25, Paper 39, Petroleum 54, Photography 36, Plant Chemistry 41, Rubber 55, Vitamins 25, Water 45.

Copies of Bulletin No. 71 may be obtained from the publication office, National Research Council, B and 21st Streets, N.W., Washington, D.C., for $1.50 a copy. Also copies of the previous Bulletin (No. 50) may be obtained from the same source for $2.50 each.